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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

WIND-TUNNEL TESTS OF A 1/6-SCALE MODEL OF REPUBLIC XF-12 VERTICAL TAIL WITH STUB FUSELAGE AND STUB HORIZONTAL TAIL

By Robert MacLachlan

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Suitable for Indexing

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— Air flow - Tail
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— Booster tabs
— Tabs, Rudder
x Rudders - Aerodynamic characteristics

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SUMMARY

A 1/6-scale model of the Republic XF-12 vertical tail with stub fuselage and stub horizontal tail was tested in the Langley stability tunnel to determine the aerodynamic characteristics of the model. The investigation included a study of the effects of boundary-layer thickness, rudder area, and cover-plate alinement on the aerodynamic characteristics. Tuft studies were made in the vicinity of the junction of the vertical and stub horizontal tails.

The results of the investigation indicated that the flow in the vicinity of the junction of the vertical and stub horizontal tails was only slightly improved by the addition of a fillet. An increase in boundary-layer thickness produced a slight decrease in rudder effectiveness. The increase in lift of the combined rudders over that of the upper rudder alone was not proportional at low deflections and was approximately proportional at high deflections to the increase in rudder area. When the balance-chamber cover plates were bowed out, the change in rudder hinge moment with rudder angle was less negative. The variation of the lift coefficient with angle of attack and the variation, at small values of angle of attack, of rudder hinge-moment coefficient with angle of attack was approximately the same for all model configurations tested. The upper rudder used in conjunction with a tab was found to satisfy the Army specifications regarding asymmetric power on a multiengine airplane.

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$p_{(a)} - p_{(d)}$ applied pressure difference across vents of internal balance.

F overhang factor of complete rudder $\left[\left(\frac{\bar{c}_b}{\bar{c}_r}\right)^2 - \left(\frac{\bar{t}/2}{\bar{c}_r}\right)^2\right] \frac{b_b}{b_r}$

F_1 overhang factor for rudder tip chamber (correspondingly F_2, F_3, and F_4) $\left[\left(\frac{\bar{c}_{b_1}}{\bar{c}_r}\right)^2 - \left(\frac{\bar{t}_1/2}{\bar{c}_r}\right)^2\right] \frac{b_{b_1}}{b_r}$

L lift of model, pounds

H hinge moment of control; positive when tending to rotate the trailing edge to the left, foot-pounds

M pitching moment of model about an axis parallel to and 9.125 inches ahead of rudder hinge line, foot-pounds

D drag of model, pounds

S area of vertical-tail model (above fuselage), square feet

c local chord of vertical-tail model, feet

c' mean geometric chord of vertical-tail model, feet

$\bar{c}$ root mean square chord, feet

b span, feet

$\bar{t}$ root mean square thickness of rudder at rudder hinge axis, feet

q free-stream dynamic pressure, pounds per square foot

α angle of attack of vertical tail (angle of yaw for airplane); positive when trailing edge is deflected to the left, degrees

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of the Langley stability tunnel are shown in figure 4. The model which consists of the vertical tail, a stub fuselage, and a stub horizontal tail was supplied by the Republic Aviation Corporation. Figure 2 is a sketch which gives the principal model dimensions. The tab gap (see fig. 3) was unsealed for all the tests.

The geometric characteristics of the model are given in table I. Table II presents the ordinates of the vertical-tail airfoil contour. The airfoil section contour was constant over the span of the vertical tail. Table III gives the plan-form ordinates of the vertical-tail model. These ordinates differ from those of the Republic XF-12 airplane, because the dorsal fin on the airplane was omitted from the vertical-tail model.

The rudder of the model consisted of two sections: one above the horizontal tail and one below. For convenience, these two sections of the rudder have been termed, respectively, the "upper rudder" and "lower rudder"; when the two are used together they are referred to as the "combined rudders." The lower rudder could be disconnected from the upper rudder and locked into place on the fin, thus reducing the rudder area.

Details of the internal-balance cover plates and the internal balance are shown in figures 2 and 3, respectively. The internal balance of the upper rudder was contained in three spanwise chambers separated from one another at the hinges. The internal balance of the lower rudder was contained in one chamber. The nose and ends of the balance in each chamber were sealed to the front of the balance chamber and sides of the hinges, respectively, with a continuous strip of koroseal coated voile. During some preliminary tests on the model, it was noted that the cover plates were bowed out between the hinges of several of the balance chambers; thus, the vent gaps were somewhat larger than those corresponding to the normal model condition (the condition in which the cover plates conformed to the true airfoil contour of the tail surface.) The cover plates were subsequently adjusted to the normal condition. In the process of obtaining the adjustment, data were obtained for the model having three different amounts of cover-plate misalinement as well as for the normal condition. The four alinements of the cover plates have been designated by four terms: normal, bowed-in slightly,

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All tests were made at a dynamic pressure of 64.3 pounds per square foot. The corresponding airspeed under standard sea-level atmospheric conditions was 159 miles per hour and the Reynolds number based on the mean geometric chord of the model was about 3,300,000.

Measurements of the lift, drag, and pitching moment of the model were obtained from the tunnel balances. Rudder hinge moments were measured by means of a spring-torque balance linked to the rudder; tab hinge moments were measured by means of a strain gage mounted in the upper rudder. Readings of the pressure differences across the balance in each of the three upper rudder internal-balance chambers were taken when the upper rudder alone was utilized. When the combined rudders were used, only the reading of the pressure difference across the balance in the lower rudder internal-balance chamber was taken.

The leakage factor E was measured for each of the four internal-balance chambers in the same manner as is described in reference 1.

Jet-boundary corrections to the lift, rudder hinge moment, pitching moment, drag, pressure difference across the balance, and angle-of-attack readings were determined by the general methods described in reference 2. These corrections applied (by addition) to the tunnel data are as follows:

	Upper rudder	Combined rudders
$\Delta\alpha$	$1.45C_L + 0.51(C_L)_{\delta_r=\delta_t=0}$	$1.70C_L + 0.26(C_L)_{\delta_r=\delta_t=0}$
ΔC_L	$-0.0102C_L$	$-0.0102C_L$
ΔC_D	$.0282{C_L}^2$	$.0295{C_L}^2$
ΔC_m	$.0062C_L$	$.0062C_L$
$\Delta(\Delta P)_1$	$-.0028C_L$	$-.0028C_L$
$\Delta(\Delta P)_2$	$-.0040C_L$	$-.0040C_L$
$\Delta(\Delta P)_3$	$-.0051C_L$	$-.0051C_L$
$\Delta(\Delta P)_4$		$-.0051C_L$

Tuft Study

The results of the tuft study of flow in the vicinity of the junction of the vertical and stub horizontal tails are given in figure 6. The photographs show the flow characteristics at the junction with and without fillets installed for several angles of attack and without fillets installed for two rudder deflections. Tufts were attached only to the vertical tail surface. The tufts which, in the photographs, appear to be attached to the horizontal tail surface are reflections from the highly polished horizontal tail surface of the tufts on the vertical tail surface. A comparison of the results indicate that the flow over the section of the rudder near the junction was only slightly improved by the addition of a fillet. It is possible that a larger fillet would further improve the flow characteristics.

Rudder Characteristics

Tests were made to determine the aerodynamic characteristics of the vertical tail with roughness strips at 0.20 chord utilizing the upper rudder alone (fig. 7) and the combined rudders (fig. 8). The data presented in figure 7 were obtained with the cover-plate alinement in the normal condition while those of figure 8 were obtained with bowed-out cover-plate alinement. To investigate the asymmetry in the C_{h_r} against δ_r curves, the rudder hinge-moment results for the upper rudder at zero angle of attack were corrected for the offset location of the rudder internal-balance plates. (See fig. 9.) The corrections were obtained by using material contained in an unpublished theoretical investigation of the hinge moments of sealed internal-balance arrangements for control surfaces. The results shown in figure 9 indicate that the major cause of the asymmetry in the C_{h_r} against δ_r curves was the off-center location of the rudder-balance plates. (See fig. 3.)

<u>Rudder area</u>.- A comparison of the results obtained for the two different rudder areas when the cover-plate alinement was in the normal condition and with roughness strips at 0.20 chord is given in figure 10. The change in rudder area had little effect on C_{L_α} and, at small

from the change in the $(\Delta P)_{\delta_r}$ values with the change in cover-plate alinement (fig. 12(b)). The magnitude of the decrease in $C_{h_{r_{\delta_r}}}$ emphasizes the necessity of careful cover-plate alinement on both model and airplane if aerodynamic characteristics are to be predicted. A more complete discussion of this effect can be found in reference 3.

Tab Characteristics

Tab tests were made of the model utilizing the upper rudder and with roughness strips located at 0.20c. The data obtained from these tests are presented in figure 13.

Figure 14 shows the effects of rudder area, boundary-layer thickness, and cover-plate alinement on the tab characteristics. The results are presented as increments of C_L, C_{h_r}, and C_{h_t}; these increments were computed by subtracting the values of the coefficients obtained with zero tab angle from the corresponding values obtained with tab angles of ±10°.

Examination of figure 14 reveals that increase in rudder area had practically no effect on tab characteristics but in the majority of cases installation of roughness strips produced decreased values of the rudder hinge-moment and tab hinge-moment increments.

Some Estimated Characteristics of the XF-12 Airplane

Under the direction of Langley flight division personnel, an analysis of the directional stability characteristics of the Republic XF-12 airplane was made at Langley by Republic Aviation Corporation personnel. The estimated variation of yawing-moment coefficient with angle of yaw without dorsal fin was corrected for the values of C_{L_α} obtained from the wind-tunnel tests of the vertical-tail model; the resulting values including the effect of dorsal fin are presented in

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CONCLUSIONS

The results of the tests on a 1/6-scale model of the XF-12 vertical tail indicated the following conclusions:

1. The flow in the vicinity of the junction of the vertical and stub horizontal tails was only slightly improved by the addition of a fillet.

2. The increase in lift of the combined rudders over the upper rudder alone was not proportional at low deflections and was approximately proportional at high deflections to the increase in rudder area.

3. Increase in boundary-layer thickness produced a slight decrease in rudder effectiveness and, when the tab was deflected, in tab hinge moment.

4. Cover-plate misalinement changed the value of the rudder hinge-moment variation with rudder deflection $C_{h_{r\delta_r}}$. With the cover plates in the bowed-out condition, the value of $C_{h_{r\delta_r}}$ was much less negative than with the cover plates in the normal condition.

5. The variation of the lift coefficient with angle of attack and the variation at small angles of attack of rudder hinge-moment coefficient with angle of attack was approximately the same for all the model configurations tested.

6. The upper rudder used in conjunction with the tab was found to satisfy the Army specifications regarding asymmetric power on a multiengine airplane.

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Physicist

Approved: Hartley A. Soulé

Hartley A. Soulé
Chief of Stability Research Division

ES

TABLE I

GEOMETRIC CHARACTERISTICS OF XF-12 VERTICAL-TAIL MODEL

Vertical tail:	
Area above fuselage, S, sq ft	5.985
Span, b, ft	3.607
Aspect ratio	2.17
Mean geometric chord, c', ft	2.215
Taper ratio	0.557
Tail volume coefficient (tail length times tail area divided by wing span times wing area)	0.0534
Trailing-edge angle, deg	15
Upper rudder:	
Area aft hinge line, sq ft	1.533
Span, b_r, ft	2.50
Root mean square chord, $\bar{c}_r$, ft	0.628
Overhang factor (excluding seal):	
Complete internal-balance chamber, F	0.0835
Root chamber, F_3	0.0461
Center chamber, F_2	0.0344
Tip chamber, F_1	0.0030
Combined rudders:	
Area aft hinge line, sq ft	1.910
Span, b_r, ft	3.014
Root mean square chord, $\bar{c}_r$, ft	0.649
Overhang factor (excluding seal):	
Complete internal-balance chamber, F	0.0810
Lower chamber, F_4	0.0162
Root chamber, F_3	0.0358
Center chamber, F_2	0.0267
Tip chamber, F_1	0.0023
Tab:	
Span, b_t, ft	1.332
Root mean square chord, $\bar{c}_t$, ft	0.151

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TABLE II

ORDINATES OF THE XF-12 VERTICAL-TAIL AIRFOIL SECTION

[Stations and ordinates are in percent of airfoil chord]

Station	Ordinate
0	0
.5	±.845
.75	±1.019
1.25	±1.270
2.50	±1.719
5.0	±2.389
7.5	±2.909
10	±3.343
15	±4.036
20	±4.561
25	±4.951
30	±5.242
35	±5.419
40	±5.498
45	±5.454
50	±5.276
55	±4.995
60	±4.622
65	±4.158
70	±3.638
75	±3.087
80	±2.489
85	±1.886
90	±1.279
95	±.646
100	±.030

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TABLE III

PLAN FORM OF THE XF-12 VERTICAL-TAIL MODEL

[Stations and ordinates are in inches]

Station from fuselage center line	Ordinates	
	Forward of rudder hinge axis	Rearward of rudder hinge axis
-4.500	----------------	0
-4.167	----------------	1.212
-3.667	----------------	2.733
-2.833	----------------	4.294
-2.00	----------------	5.368
-1.167	----------------	6.192
0	17.333	7.067
1.833	----------------	8.021
2.167	----------------	8.153
4.617	17.267	----------------
5.500	----------------	8.982
7.167	----------------	9.133
8.000	----------------	9.155
9.167	16.962	9.133
10.333	----------------	9.078
12.500	16.636	----------------
16.667	16.072	8.654
20.833	15.317	----------------
25.000	14.340	7.721
29.167	13.091	7.049
33.333	11.483	6.183
37.500	9.332	5.025
39.333	8.107	4.365
40.000	7.589	4.070
41.667	5.944	2.913
42.500	4.733	1.850
42.833	4.059	1.183
43.000	3.629	.721
43.167	3.062	.082
43.333	1.667	-1.667

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FIGURE LEGENDS

Figure 1.- Three-view drawing of Republic XF-12 airplane.

Figure 2.- Details of the 1/6-scale model of the XF-12 vertical tail surface.

Figure 3.- Typical section of XF-12 vertical tail model.

Figure 4.- The 1/6-scale model of the XF-12 vertical tail mounted in the 6 by 6-foot test section of the Langley stability tunnel.

(a) Front view showing roughness strips located at approximately 0.20c.

Figure 4.- Concluded.

(b) Rear view showing roughness strips located at approximately 0.20c.

Figure 5.- Vent gaps at the centers of the balance chambers for the various cover-plate alinements.

Figure 6.- Tuft tests of the XF-12 vertical tail model with and without plasteline fillets, $\delta_t = 0^\circ$.

(a) $\alpha = 0^\circ$, $\delta_r = 0^\circ$.

Figure 6.- Continued.

(b) $\alpha = 0^\circ$ $\delta_r = -10^\circ$.

Figure 6.- Continued.

(c) $\alpha = 0^\circ$, $\delta_r = 10^\circ$.

Figure 6.- Continued.

(d) $\alpha = 5^\circ$, $\delta_r = 0^\circ$.

Figure 6.- Continued.

(e) $\alpha = 10^\circ$, $\delta_r = 0^\circ$.

FIGURE LEGENDS - Continued

Figure 8.- Aerodynamic characteristics of the XF-12 vertical tail model with roughness strips at 0.20c. Combined upper and lower rudders utilized, cover plates in bowed-out position; $\delta_t = 0^o$.

(a) Lift coefficient.

Figure 8.- Continued.

(b) Rudder hinge-moment coefficient.

Figure 8.- Continued.

(c) Pressure coefficient across balance.

Figure 8.- Continued.

(d) Pitching-moment coefficient.

Figure 8.- Concluded.

(e) Drag coefficient.

Figure 9.- Effect of offset location of internal balance plates on rudder hinge-moment coefficients of XF-12 vertical tail model with roughness strips at 0.20c. Upper rudder alone utilized cover plates in normal position; $\alpha = 0^o$, $\delta_t = 0^o$.

Figure 10.- Aerodynamic characteristics of the XF-12 vertical tail model for two rudder areas. Roughness strips at 0.20c; cover plates in normal position; $\delta_t = 0^o$.

(a) δ_r, deg = 0.

Figure 10.- Concluded.

(b) α, deg (upper rudder) = $0 + 1.45C_L$;
α, deg (combined rudders) = $0 + 1.10C_L$

Figure 11.- Aerodynamic characteristics of the XF-12 vertical tail model for roughness strips on and off. Upper rudder alone utilized; cover plates in normal position, $\delta_t = 0^o$.

(a) δ_r, deg = 0.

FIGURE LEGENDS - Concluded

Figure 14.- Effects of various model configurations on tab characteristics of XF-12 vertical tail model.

(a) δ_r, deg = 0.

Figure 14.- Concluded.

(b) α, deg = 0.

Figure 15.- Estimated directional stability characteristics of XF-12 airplane. $\delta_r = 0^\circ$, $\delta_t = 0^\circ$, windmilling propellers.

Figure 16.- Estimated rudder deflections required to balance an asymmetric power condition at various angles of yaw of XF-12 airplane. Upper rudder alone utilized.

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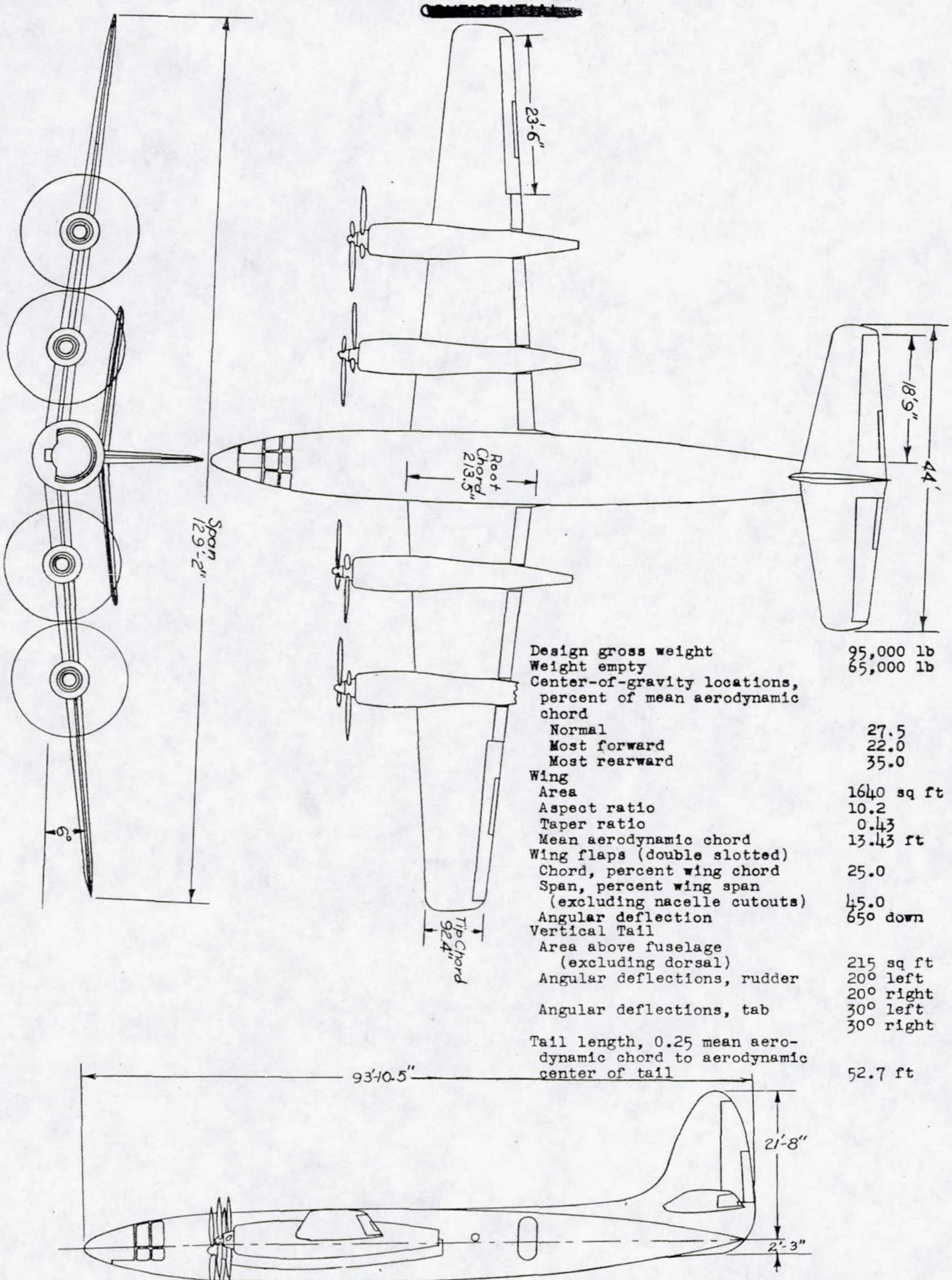

Design gross weight	95,000 lb
Weight empty	65,000 lb
Center-of-gravity locations, percent of mean aerodynamic chord	
Normal	27.5
Most forward	22.0
Most rearward	35.0
Wing	
Area	1640 sq ft
Aspect ratio	10.2
Taper ratio	0.43
Mean aerodynamic chord	13.43 ft
Wing flaps (double slotted)	
Chord, percent wing chord	25.0
Span, percent wing span (excluding nacelle cutouts)	45.0
Angular deflection	65° down
Vertical Tail	
Area above fuselage (excluding dorsal)	215 sq ft
Angular deflections, rudder	20° left 20° right
Angular deflections, tab	30° left 30° right
Tail length, 0.25 mean aerodynamic chord to aerodynamic center of tail	52.7 ft

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Figure 1 .- Three-view drawing of Republic XF-12 airplane.

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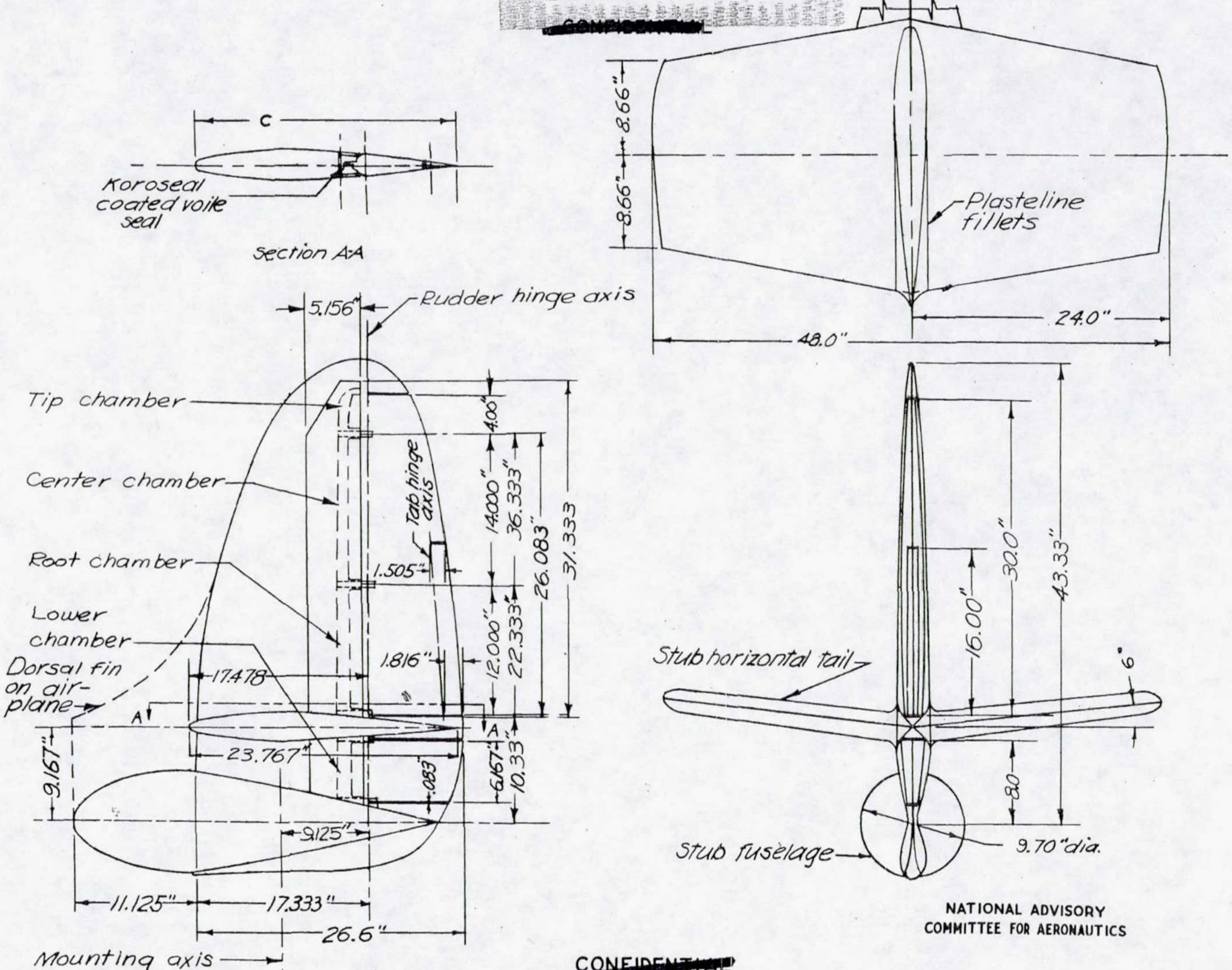

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Figure 2.- Details of the 1/6-scale model of the XF-12 vertical tail surface.

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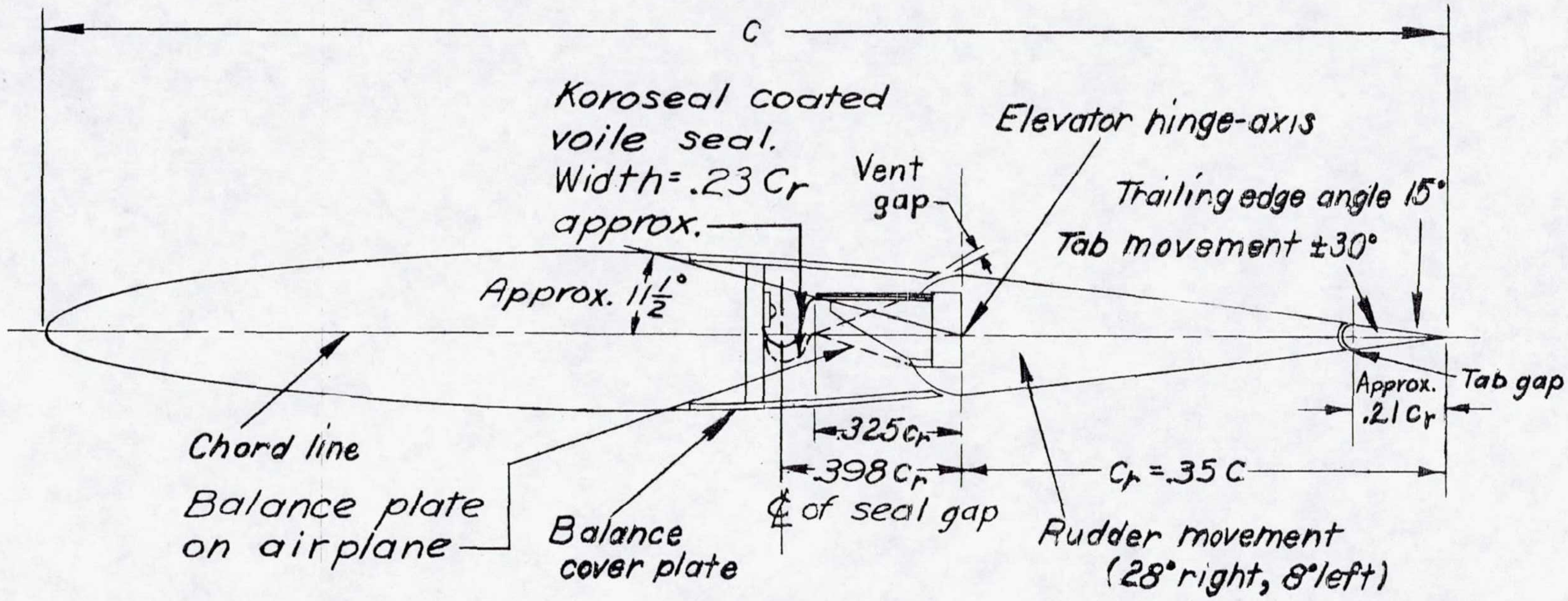

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Figure 3.- Typical section of XF-12 vertical tail model.

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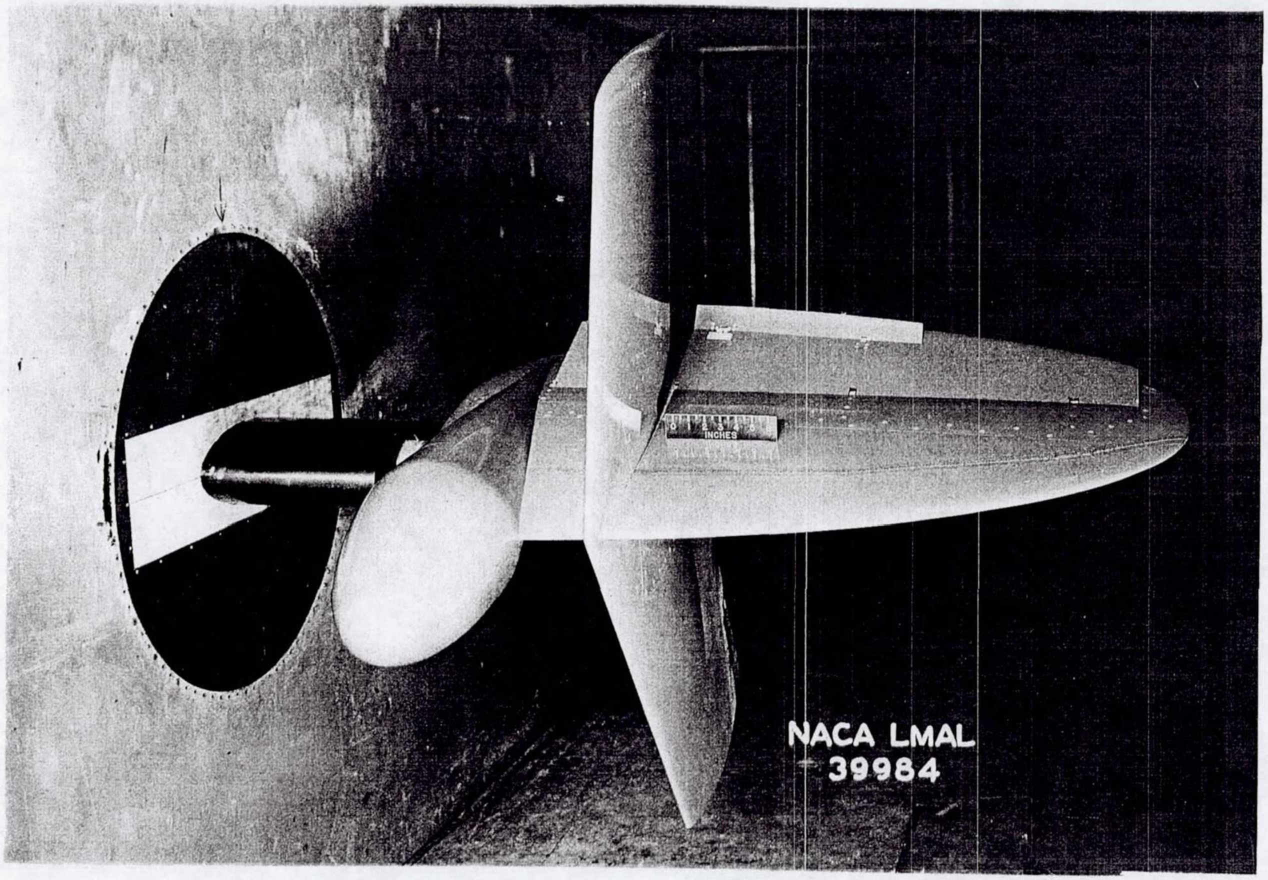
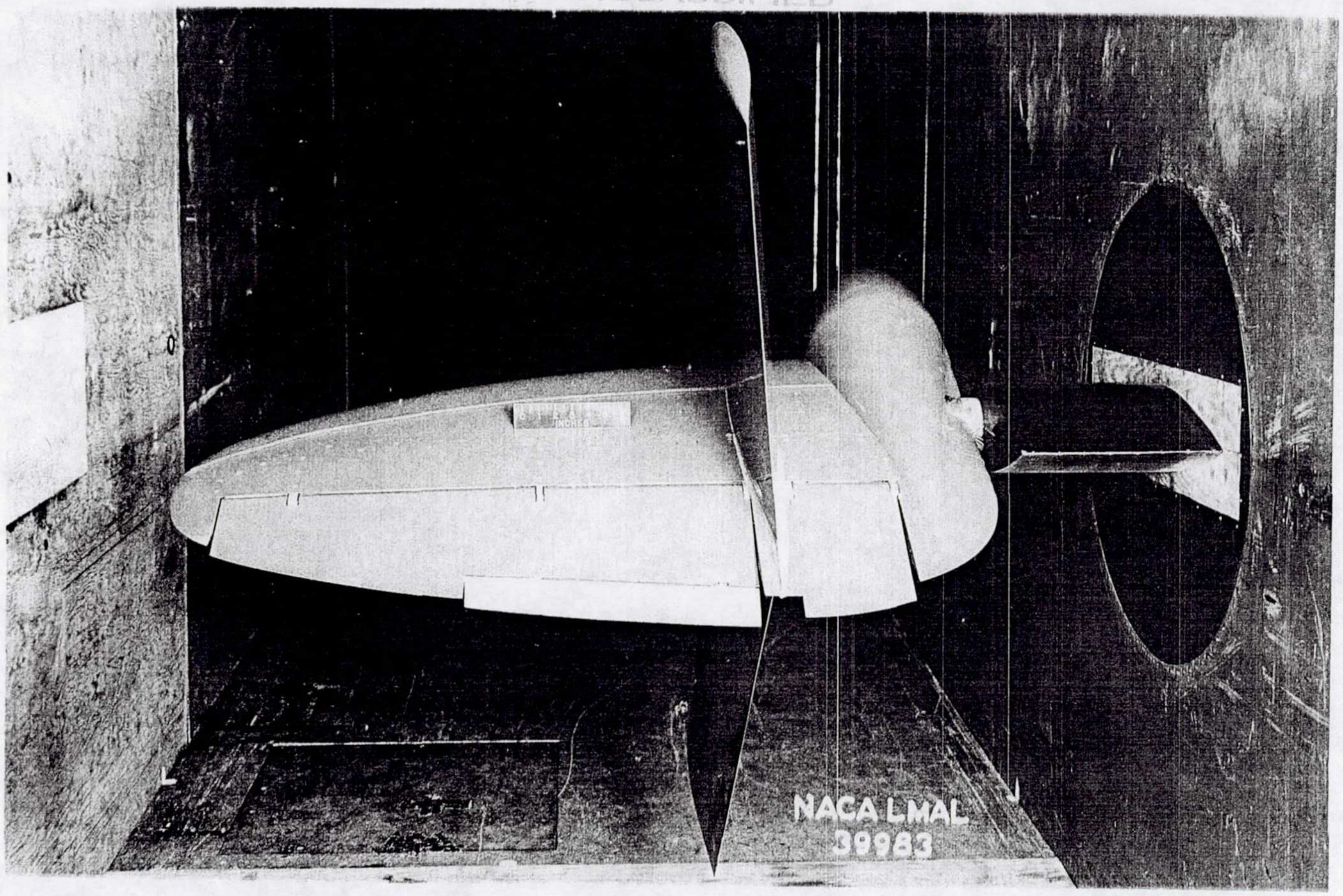


(a) Front view showing roughness strips located at approximately 0.20c.

Figure 4.- The $\frac{1}{6}$-scale model of the XF-12 vertical tail mounted in the 6 by 6-foot test section of the Langley stability tunnel.



(b) Rear view showing roughness strips located at approximately 0.20c.

Figure 4.- Concluded.

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For all tests the vent gaps at the tip, lower, and right root chambers were approximately 0.07 inch.

Vent gaps at all rudder hinges for all tests were approximately 0.07 inch.

Cover plate:	Approximate maximum vent gap (in.) Chamber - right center	left center	left root
normal	0.07	0.07	0.07
bowed-in slightly	0.07	0.05	0.07
bowed-out slightly	0.07	0.09	0.08
bowed-out	0.09	0.12	0.10

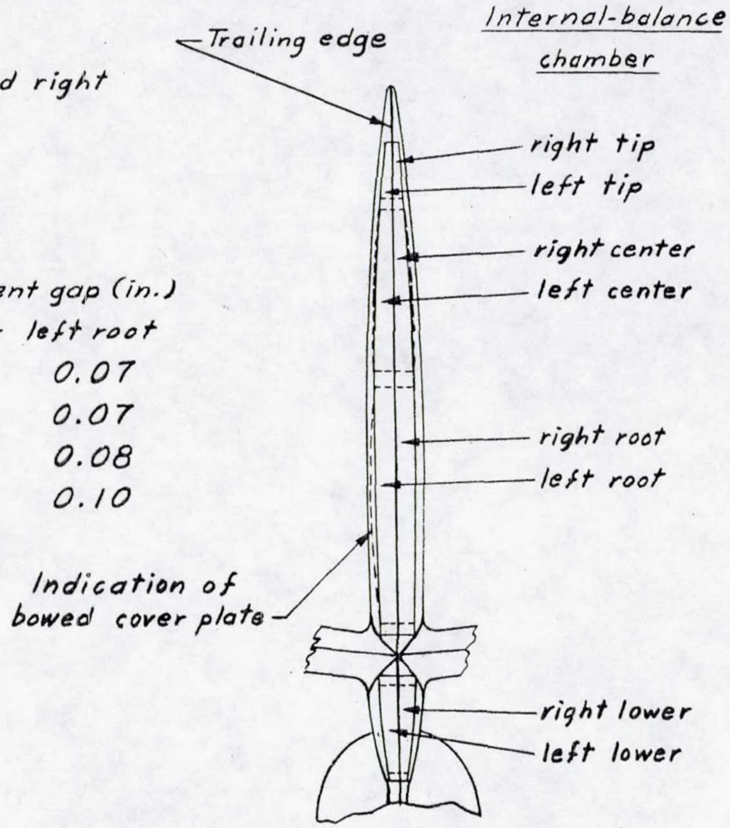

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Figure 5.— Vent gaps at the centers of the balance chambers for the various cover-plate alinements.

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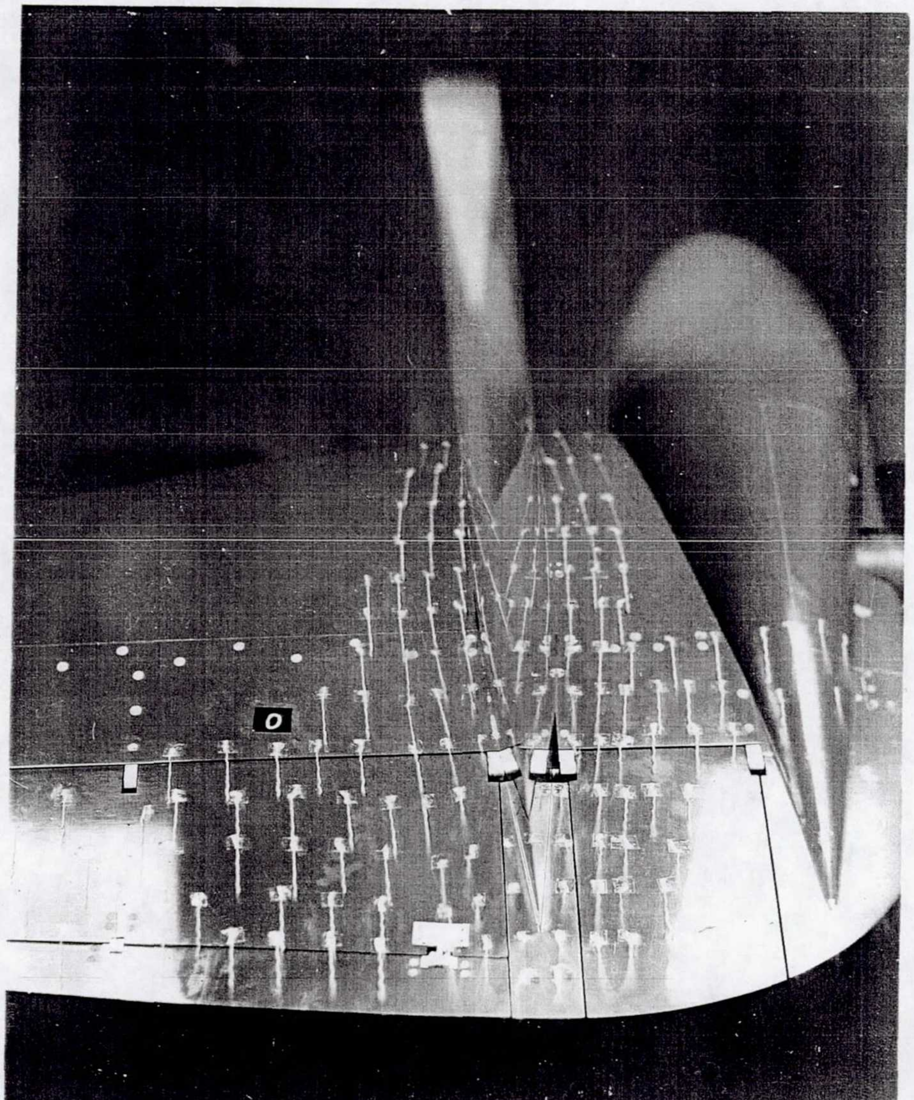

(a) $\alpha = 0^{\circ}$, $\delta_r = 0^{\circ}$.

Figure 6.- Tuft tests of the XF-12 vertical tail model with and without plasteline fillets, $\delta_t = 0^{\circ}$.

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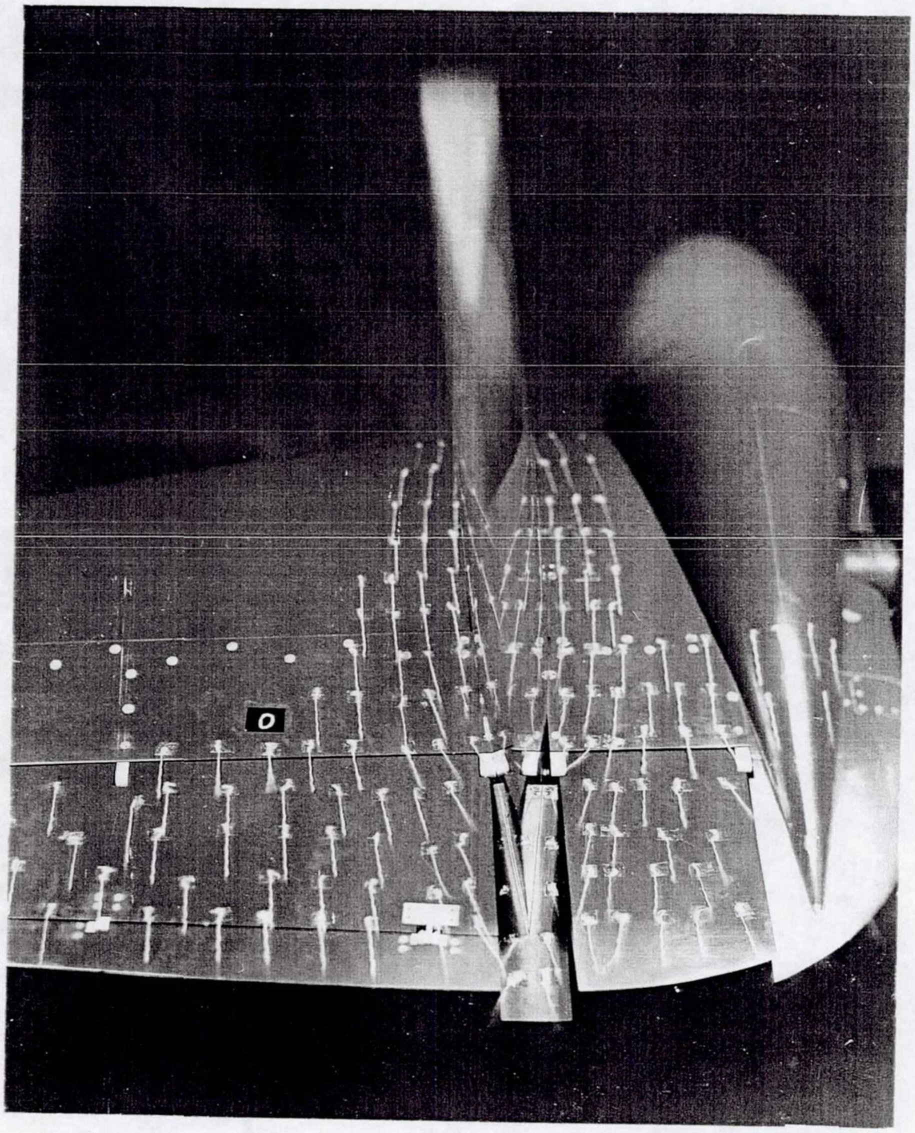

(b) $\alpha = 0^{\circ}$, $\delta_r = -10^{\circ}$.

Figure 6.- Continued.

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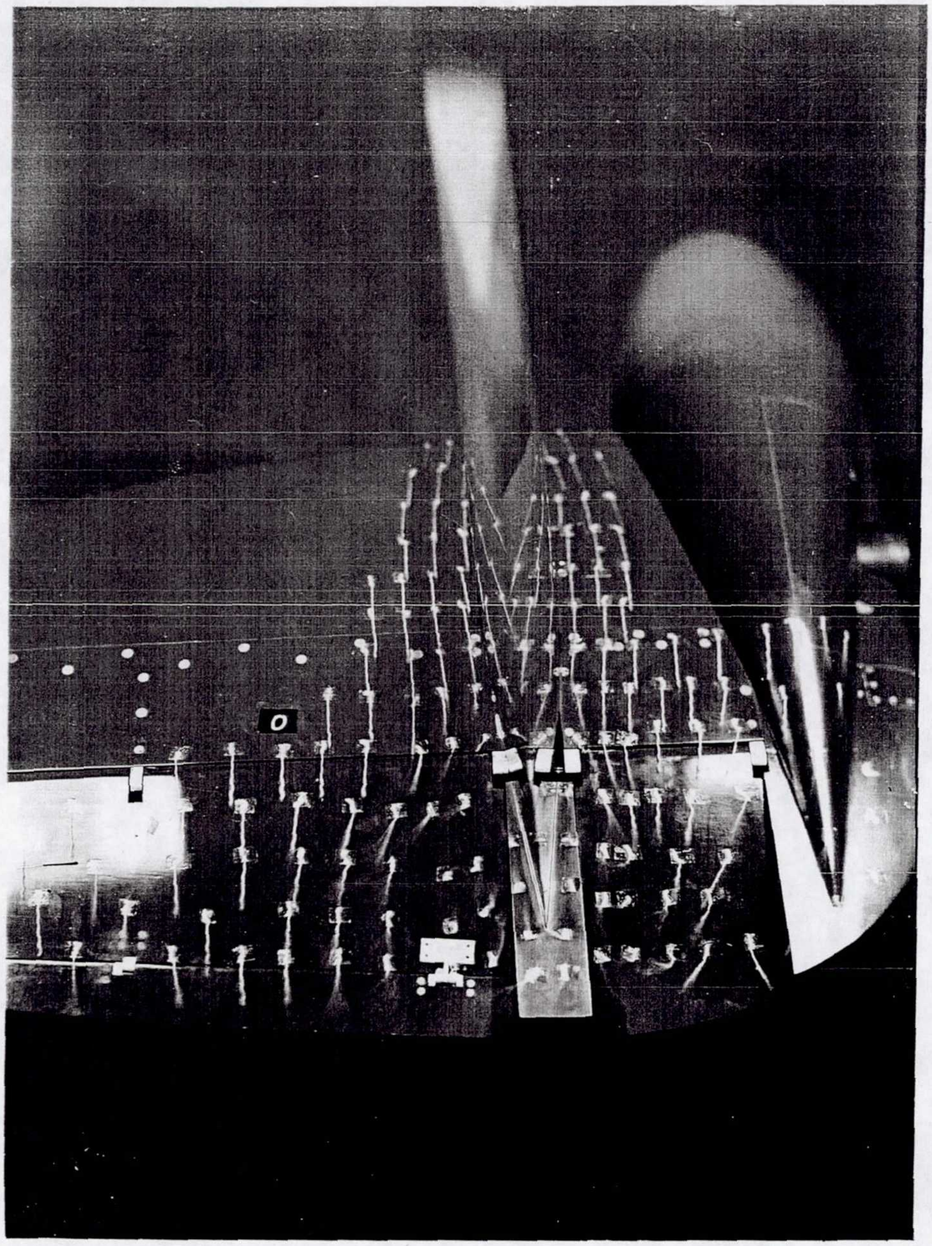

(c) $\alpha = 0^{\circ}$, $\delta_r = 10^{\circ}$.

Figure 6.- Continued.

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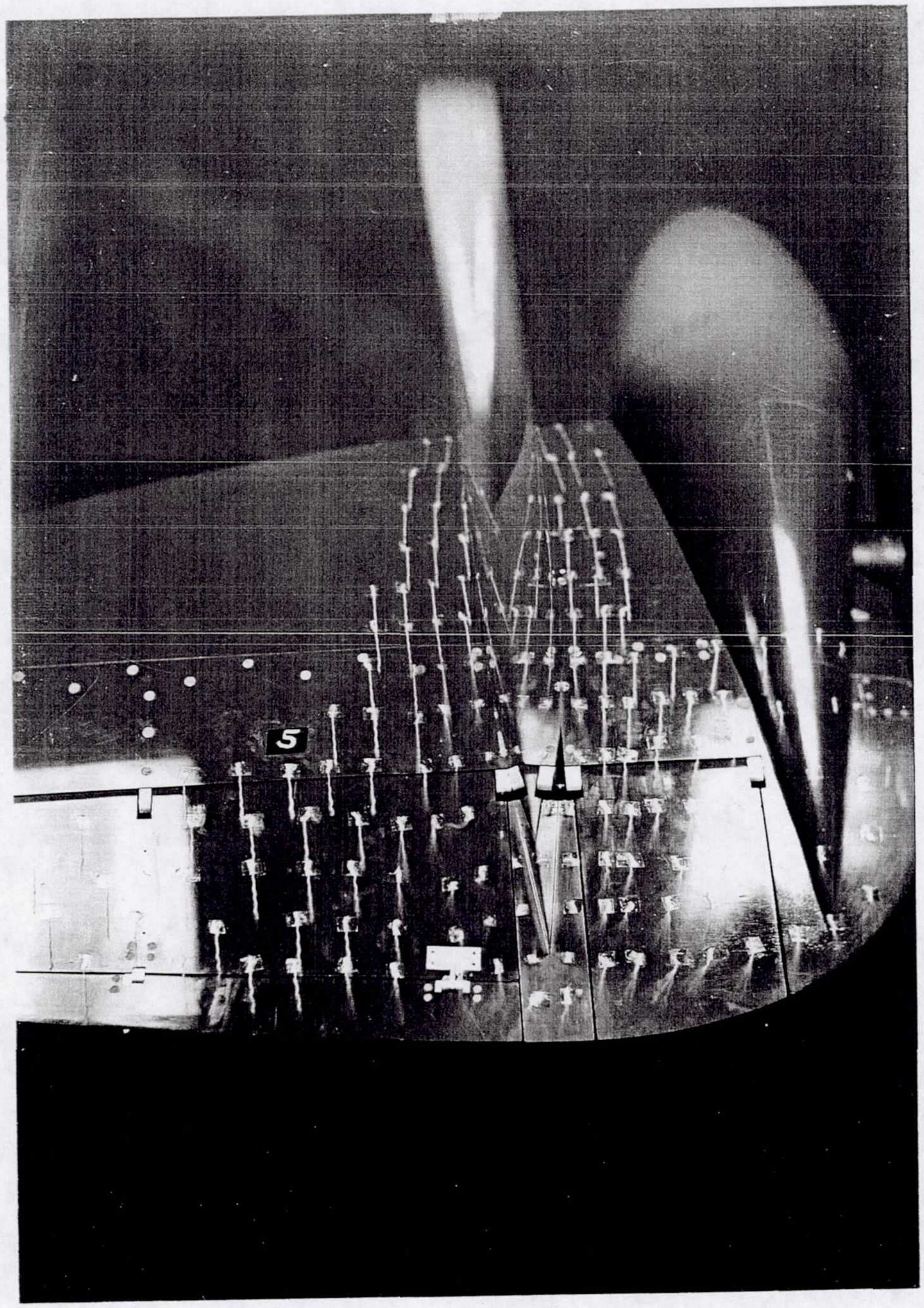

(d) $\alpha = 5^{\circ}$, $\delta_r = 0^{\circ}$.

Figure 6.- Continued.

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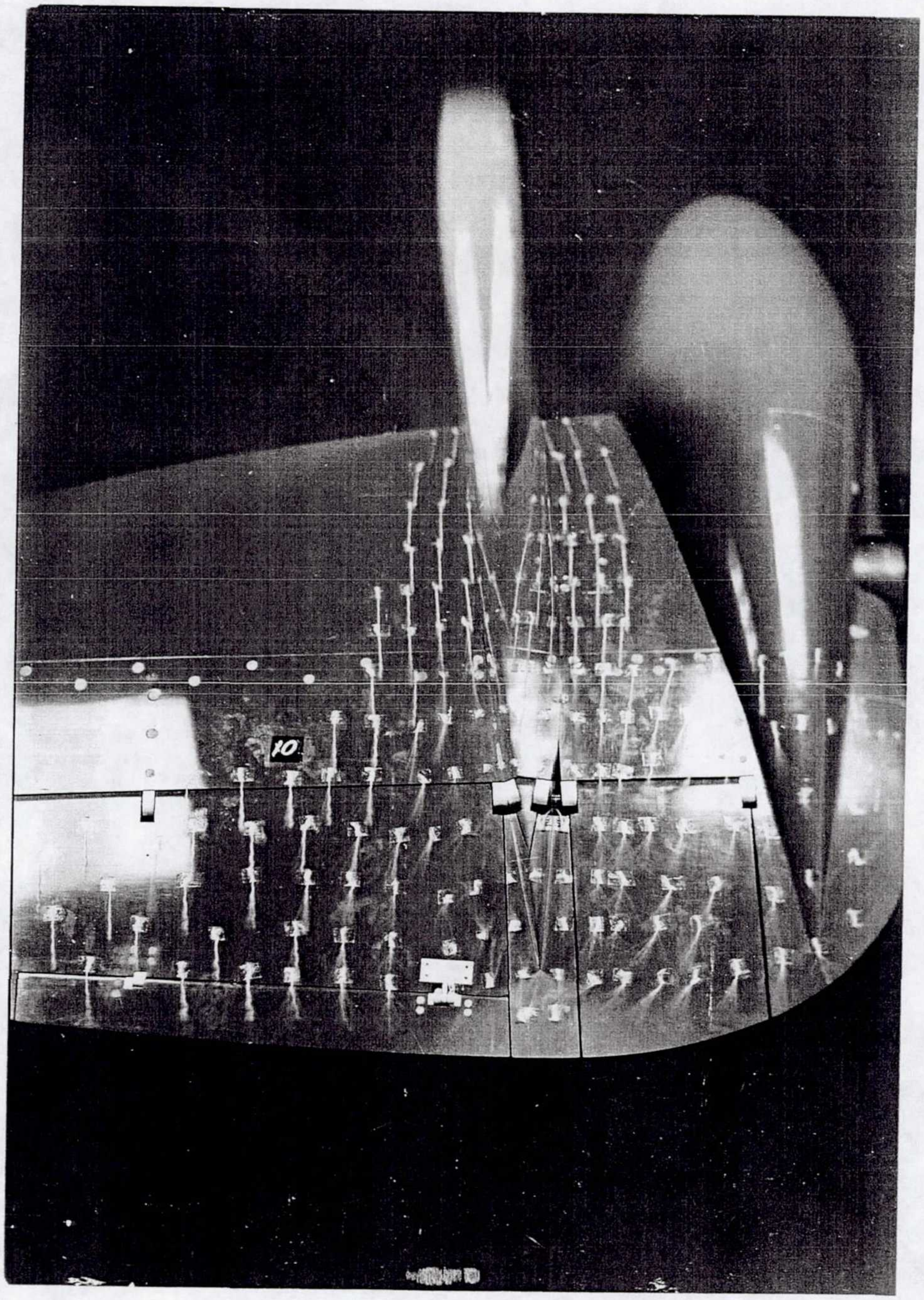
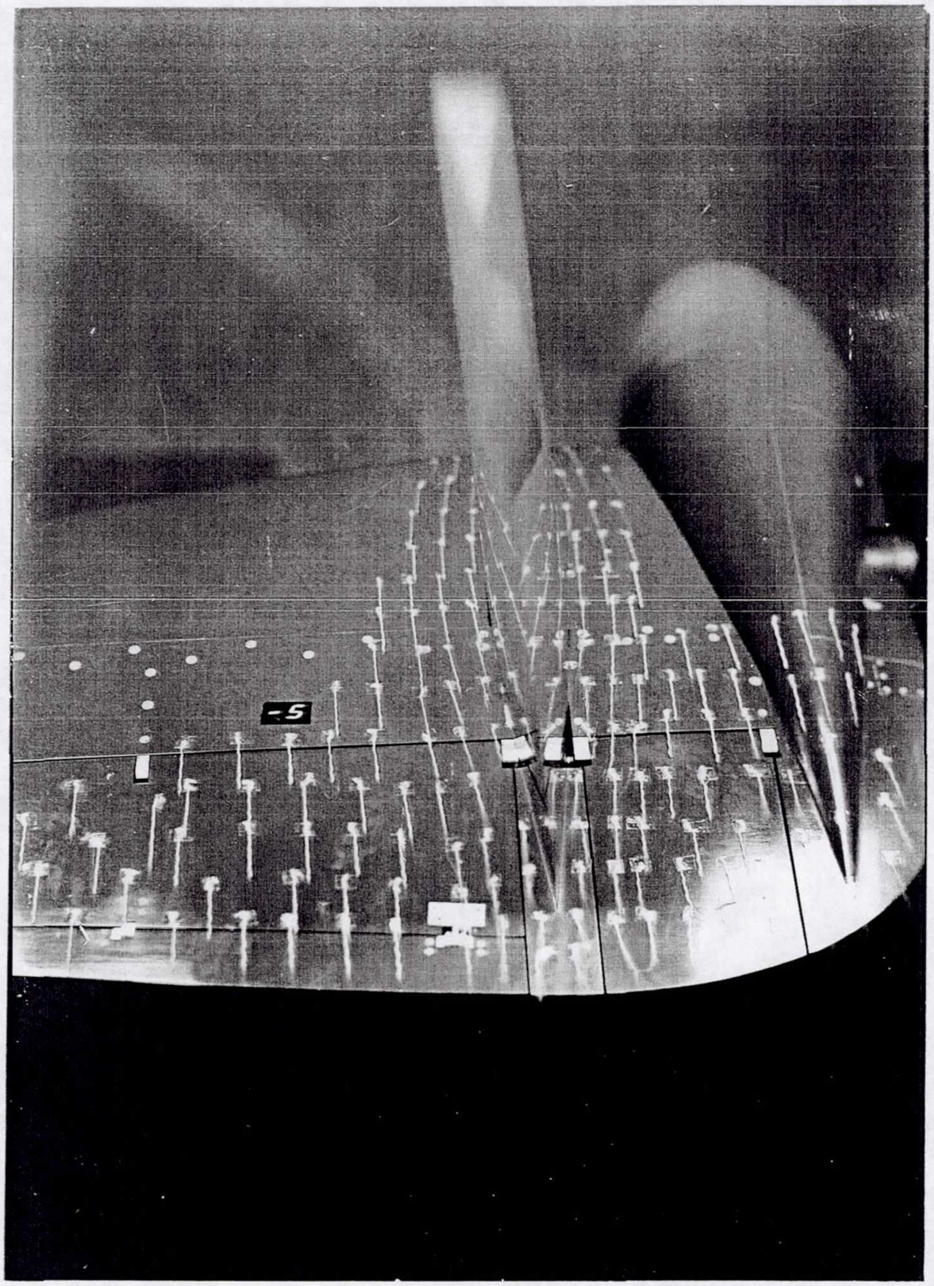


(e) $\alpha = 10^{\circ}$, $\delta_r = 0^{\circ}$.

Figure 6.- Continued.



(f) $\alpha = -5^{\circ}$, $\delta_r = 0^{\circ}$.

Figure 6.- Continued.

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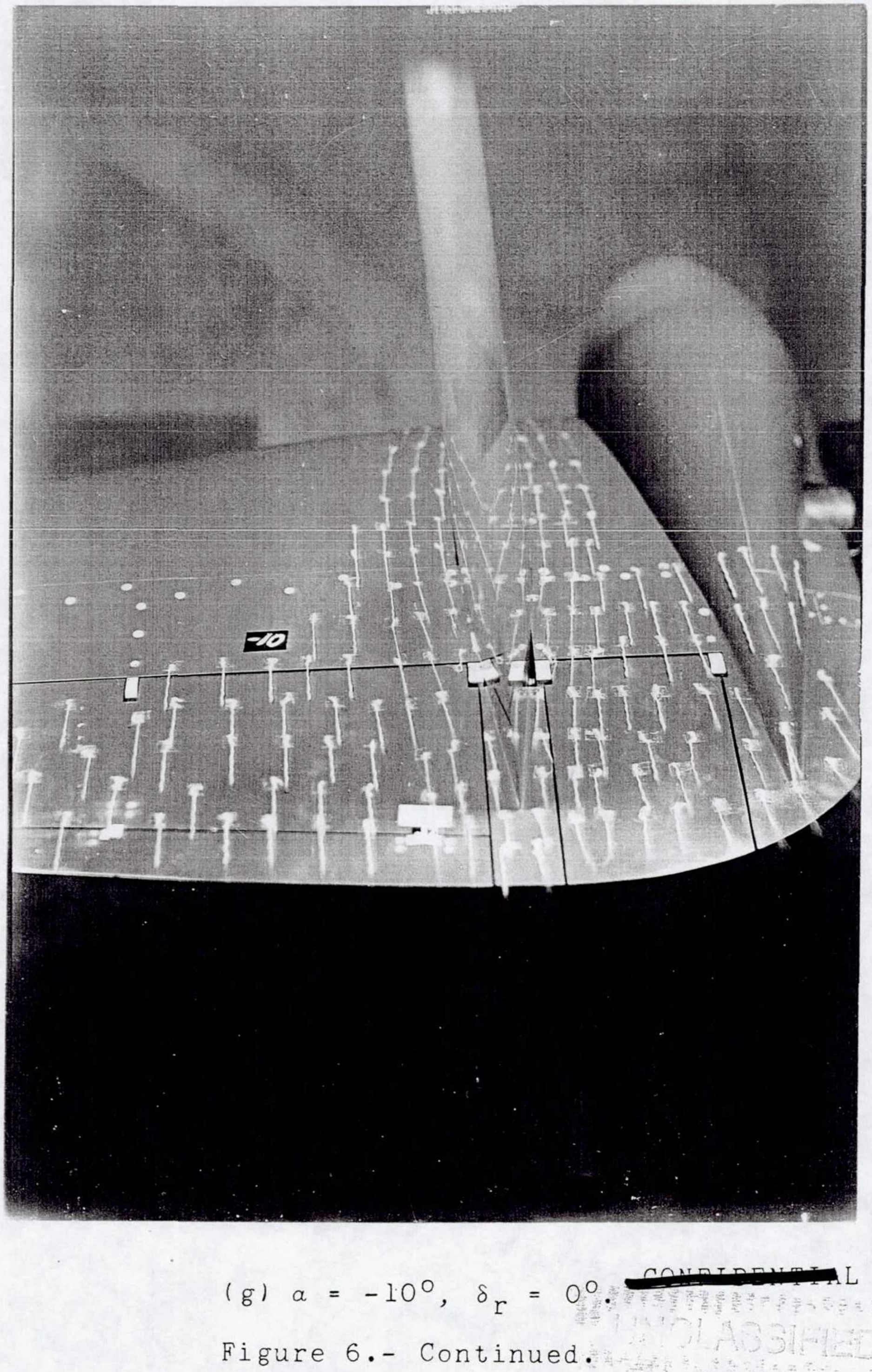
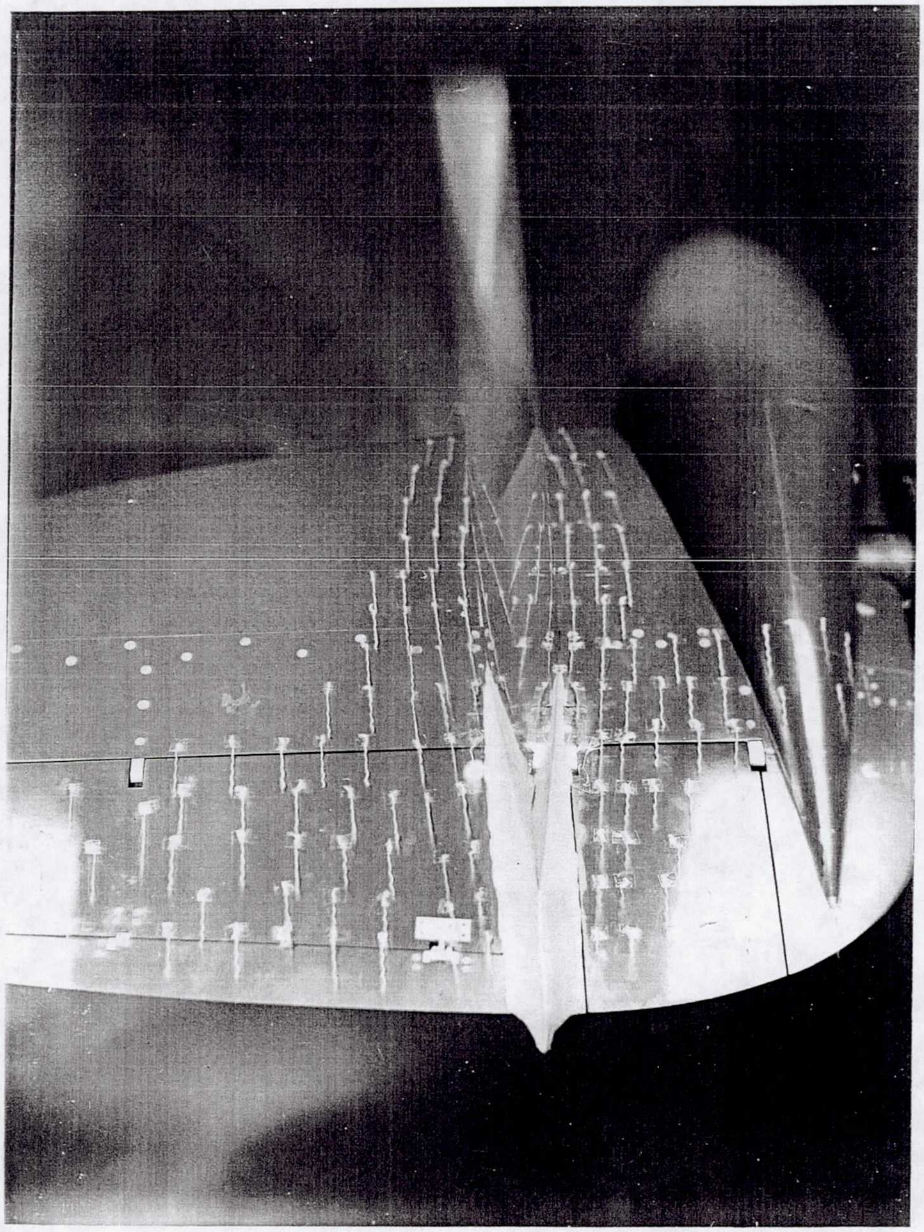


(g) $\alpha = -10^{\circ}$, $\delta_r = 0^{\circ}$.

Figure 6.- Continued.



(h) $\alpha = 0^{o}$, $\delta_r = 0^{o}$, fillets installed.

Figure 6.- Continued.

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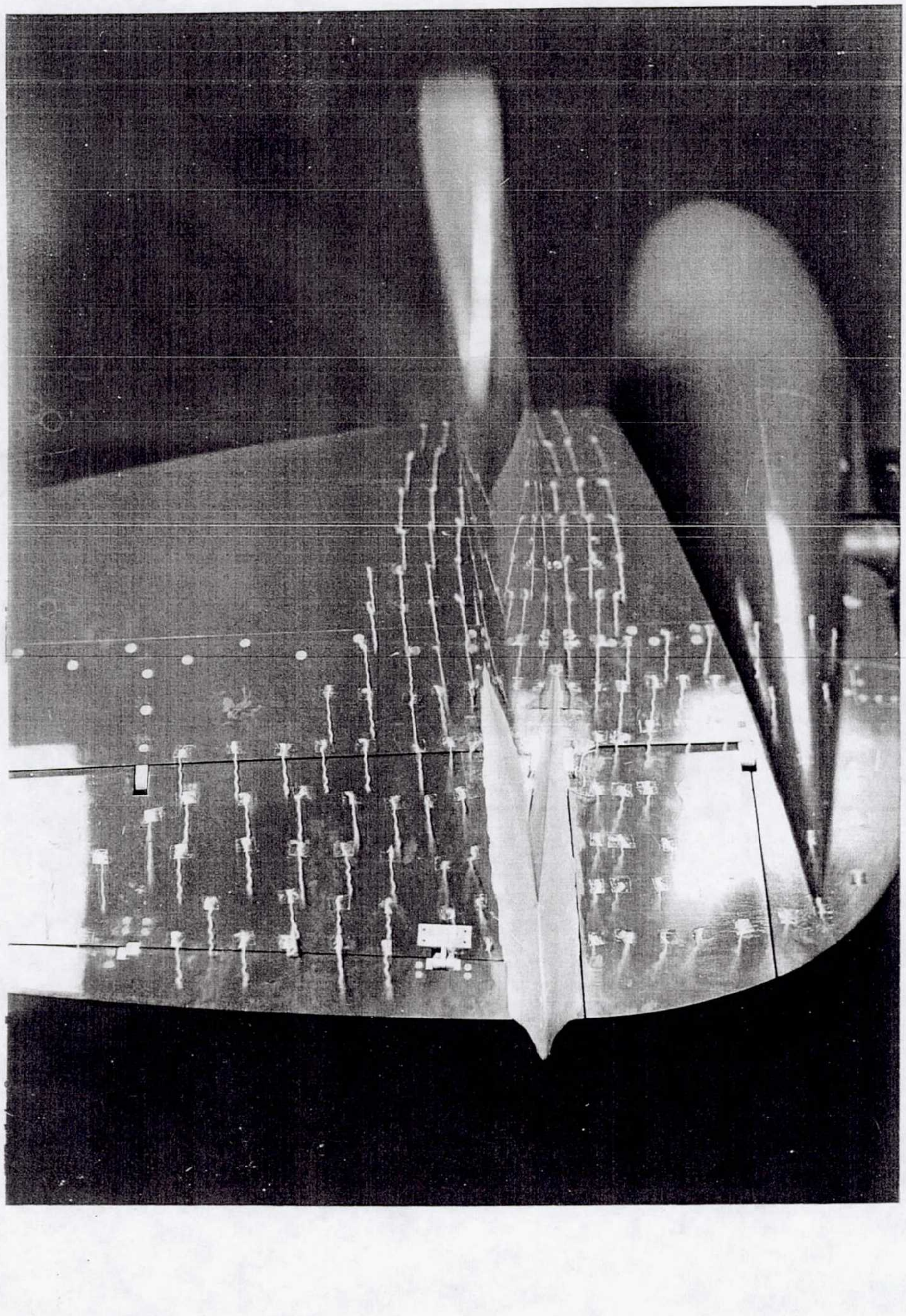

(i) $\alpha = 5^{\circ}$, $\delta_r = 0^{\circ}$, fillets installed.

Figure 6.- Continued.

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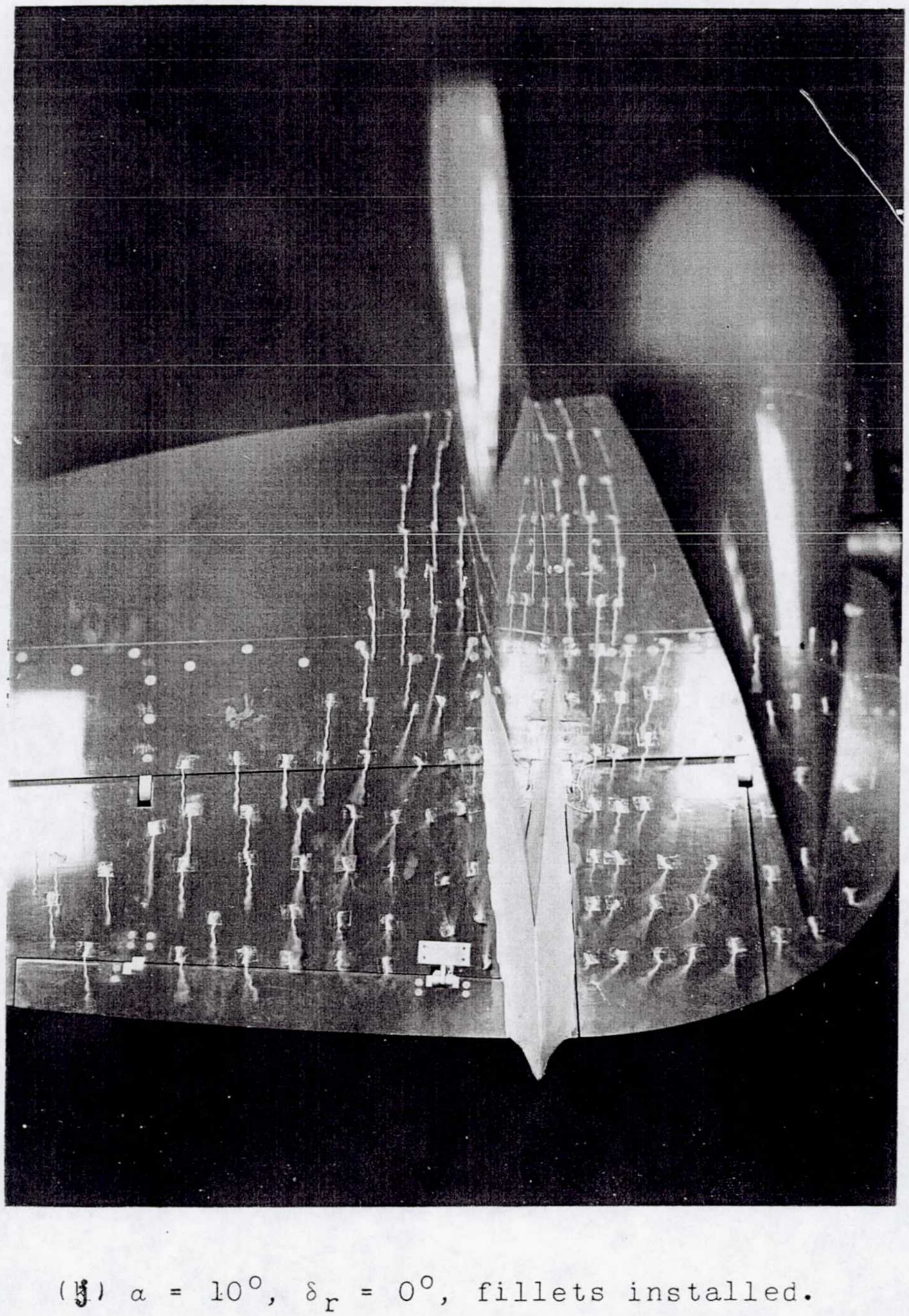
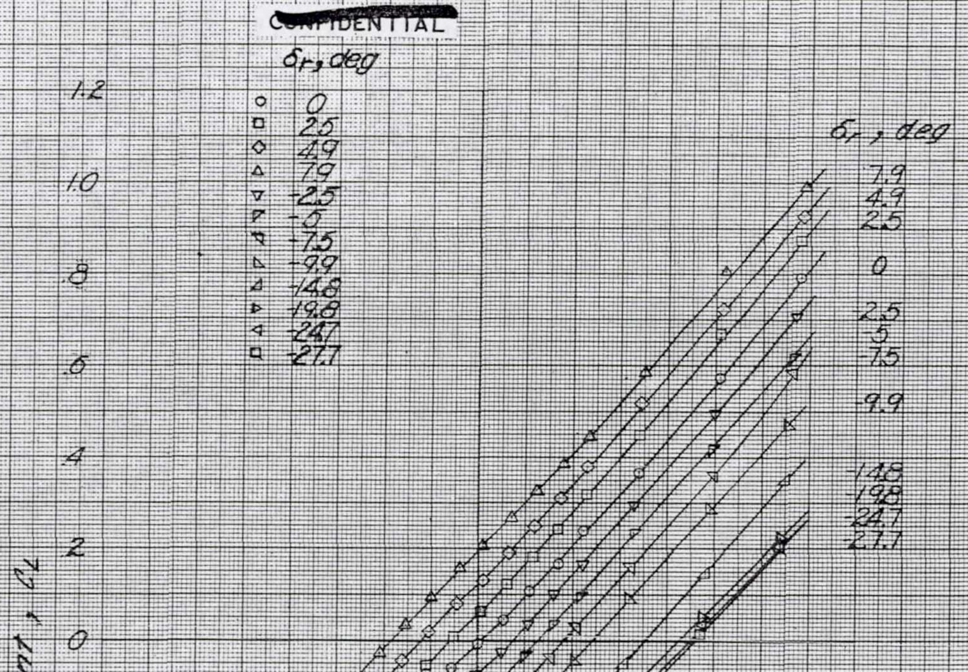


(j) $\alpha = 10^{\circ}$, $\delta_r = 0^{\circ}$, fillets installed.

Figure 6.- Concluded.



(a) Lift coefficient.

Figure 7.- Aerodynamic characteristics of the XF-12 vertical tail model with roughness strips at 0.20c. Upper rudder alone utilized; cover plates in normal position; $\delta_t = 0°$.

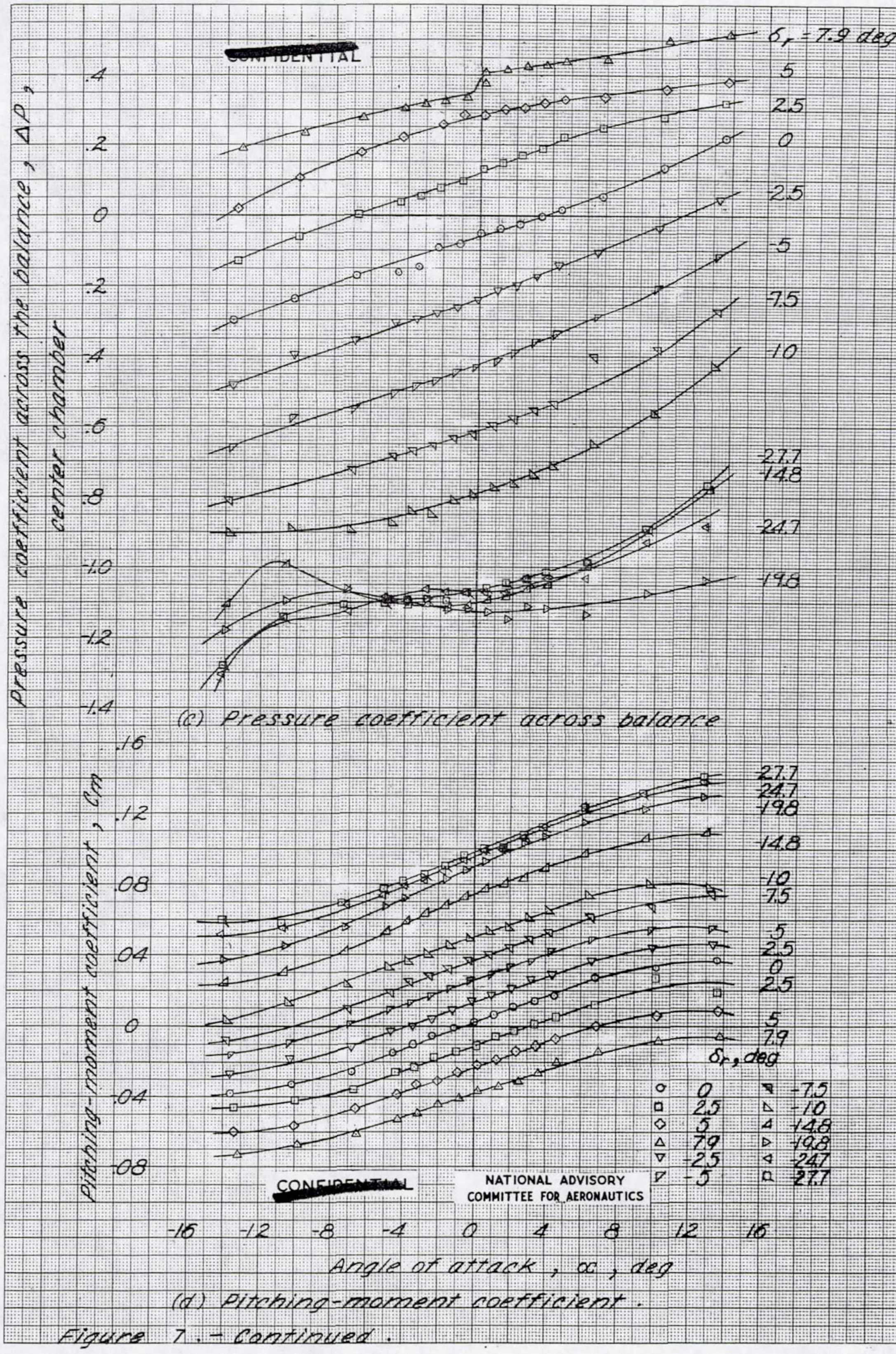
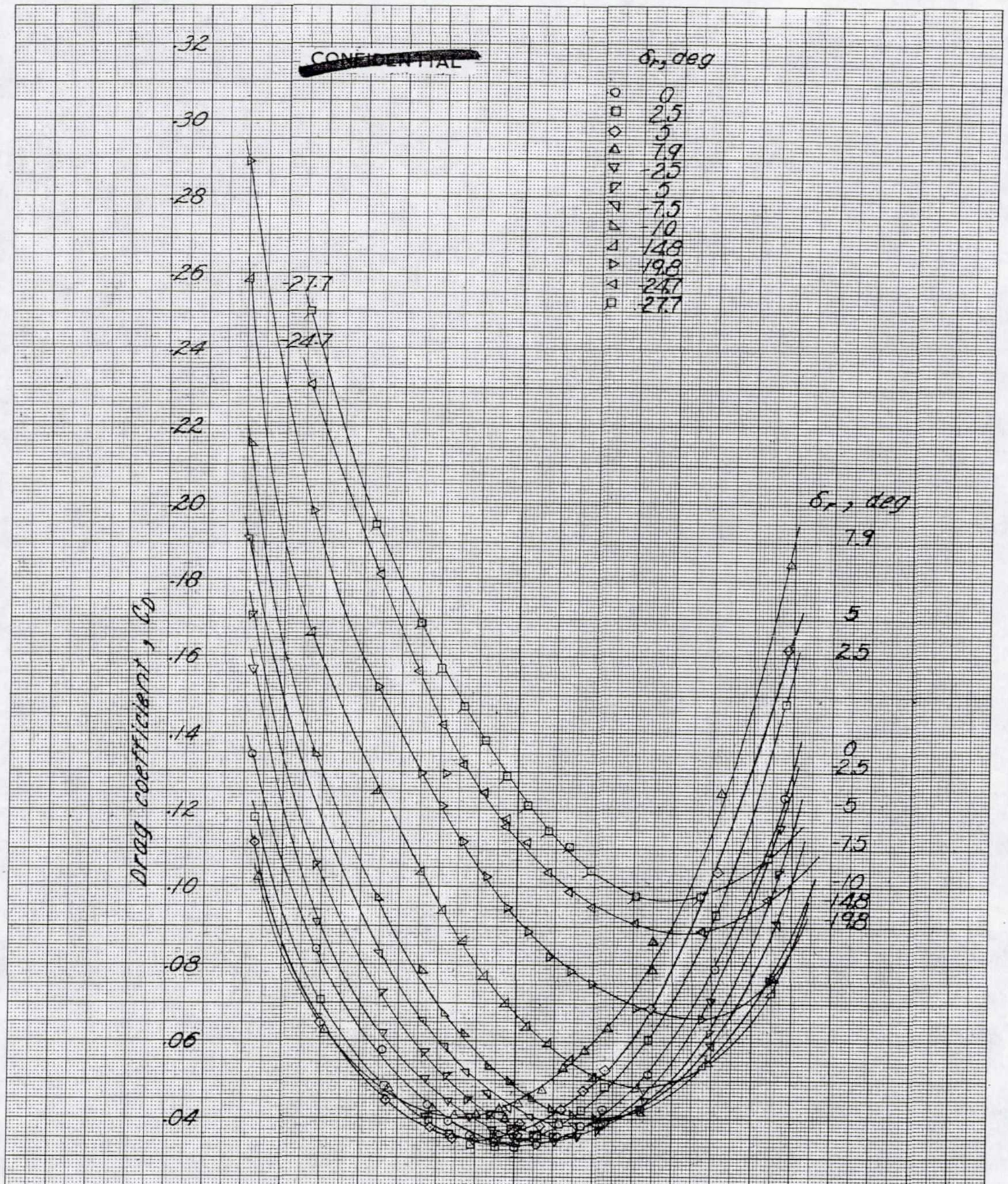
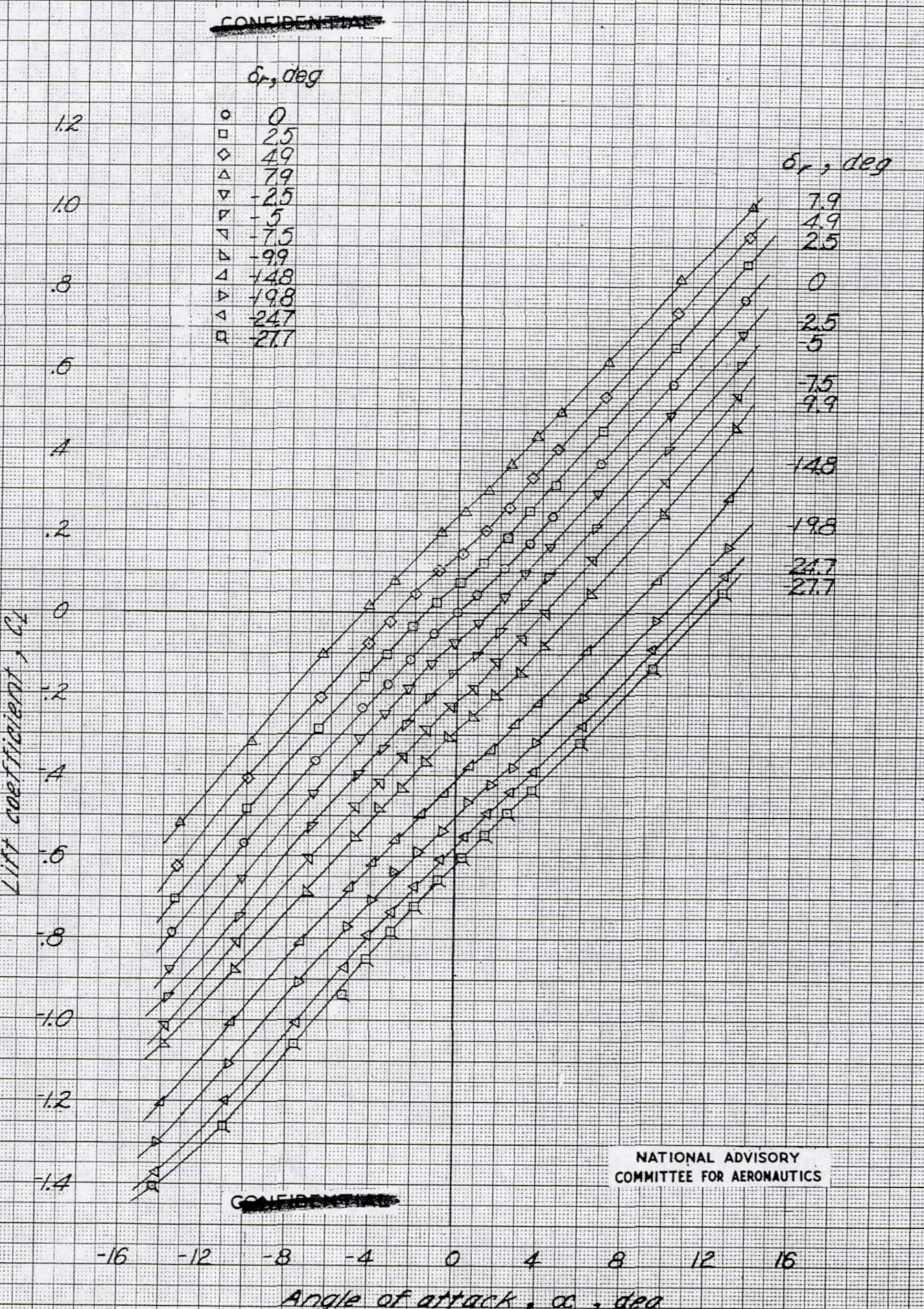


Figure 7.- Continued.



(e) Drag coefficient.

Figure 7.- Concluded.



(a) Lift coefficient.

Figure 8.- Aerodynamic characteristics of the XF-12 vertical tail model with roughness strips at 0.20c. Combined upper and lower rudders utilized; cover plates in bowed-out position; $\delta_t = 0°$.

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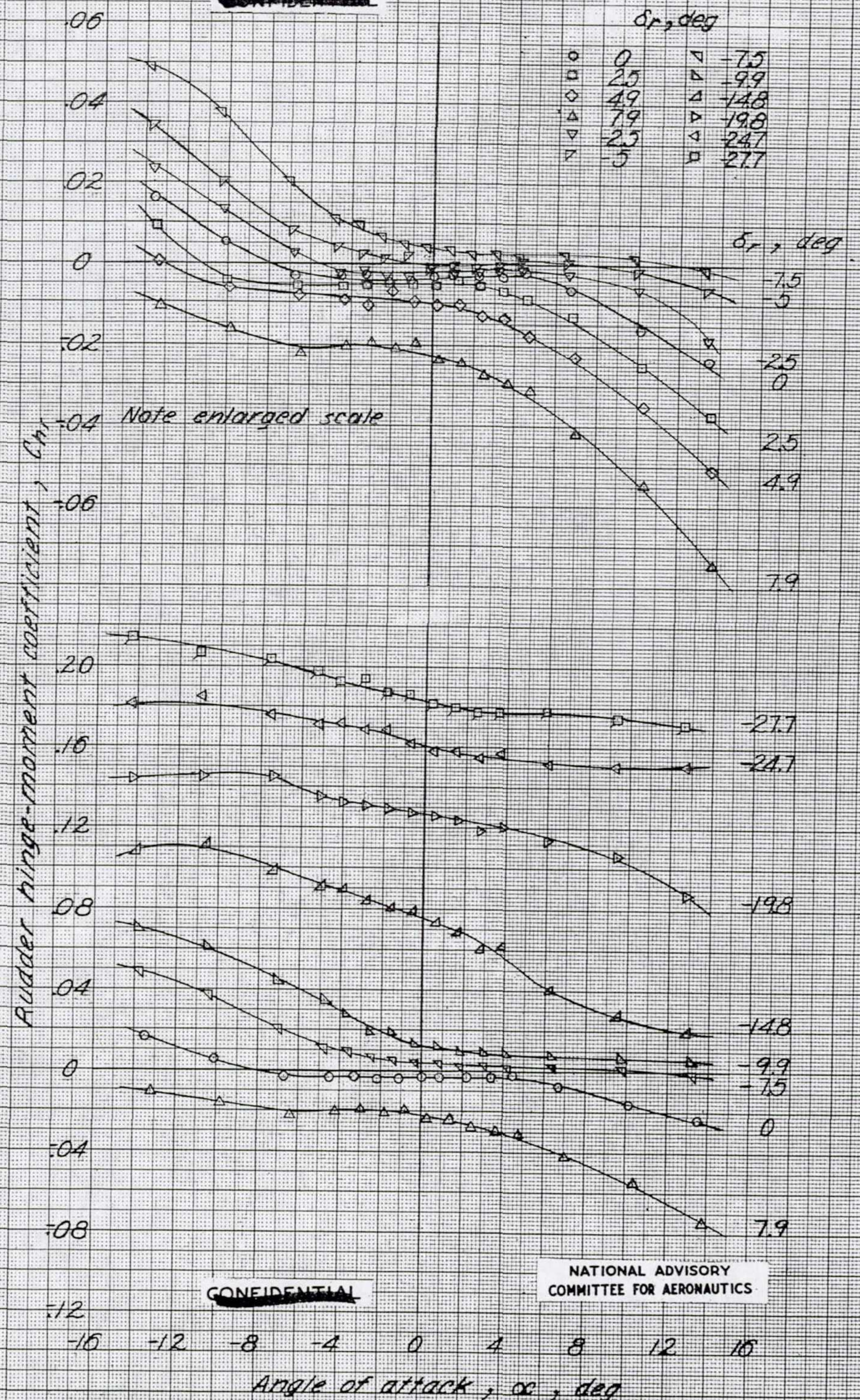

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(b) Rudder hinge-moment coefficient.

Figure 8 .- Continued.

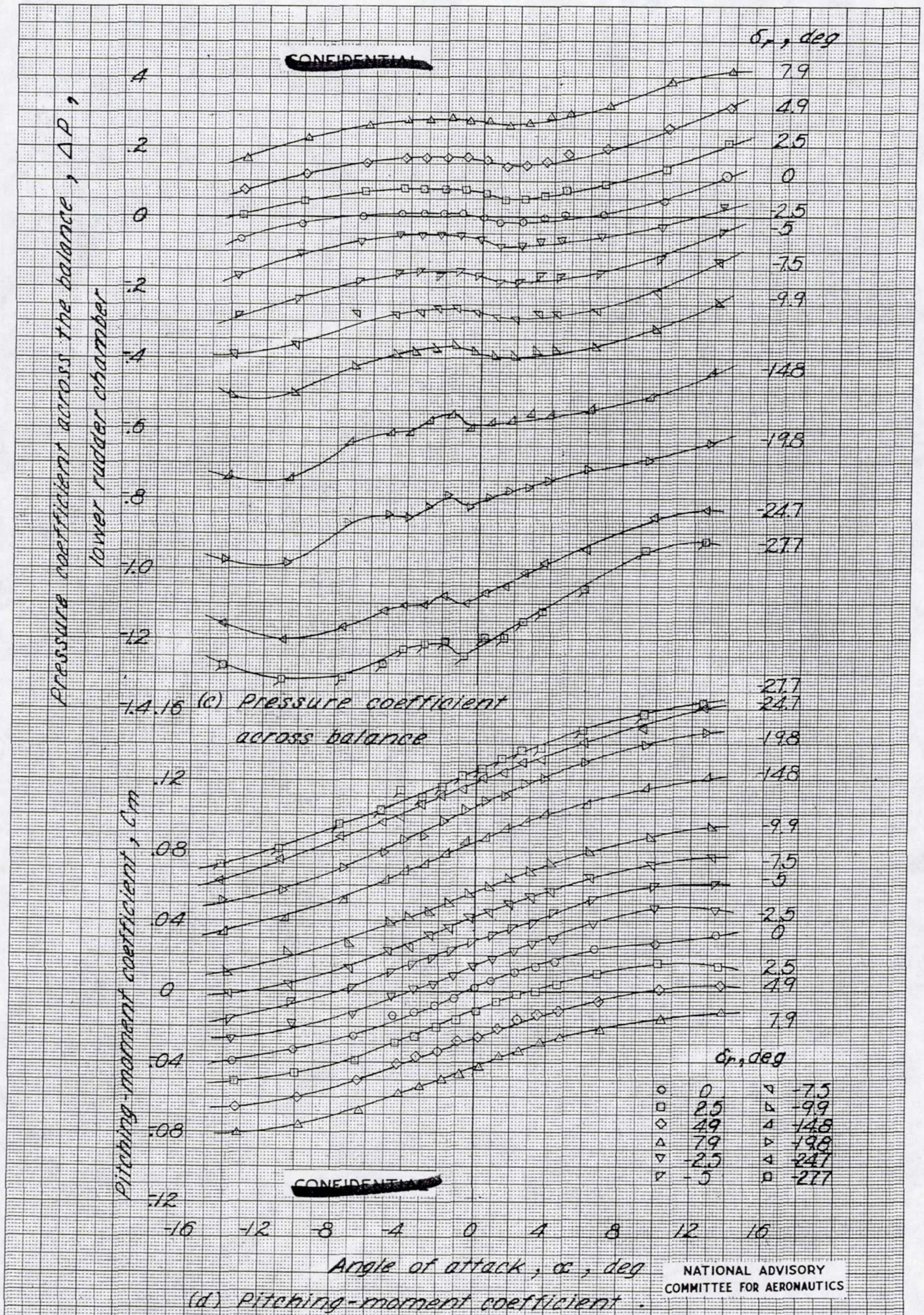
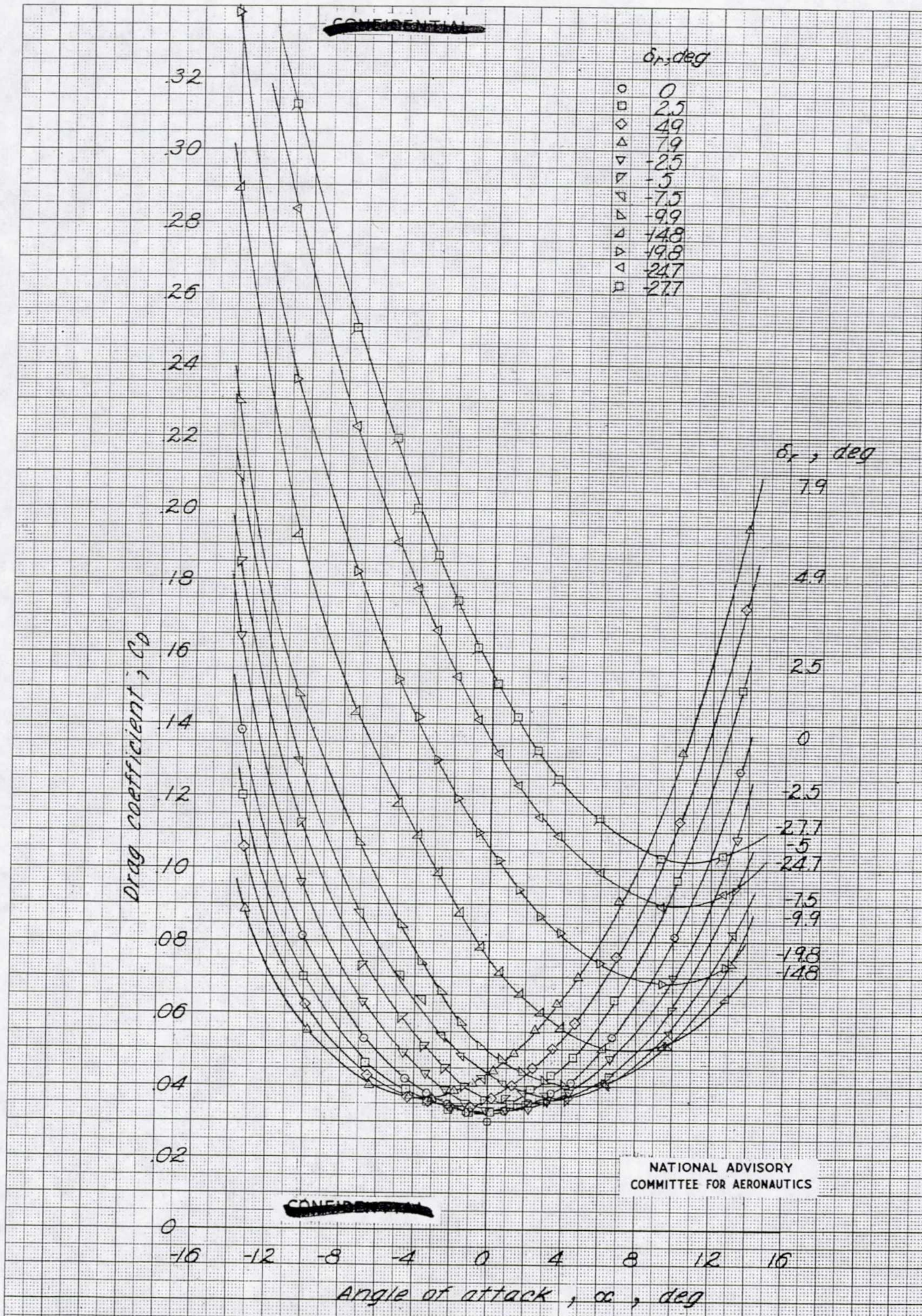


Figure 8.- Continued.



(e) Drag coefficient.

Figure 8.- Concluded.

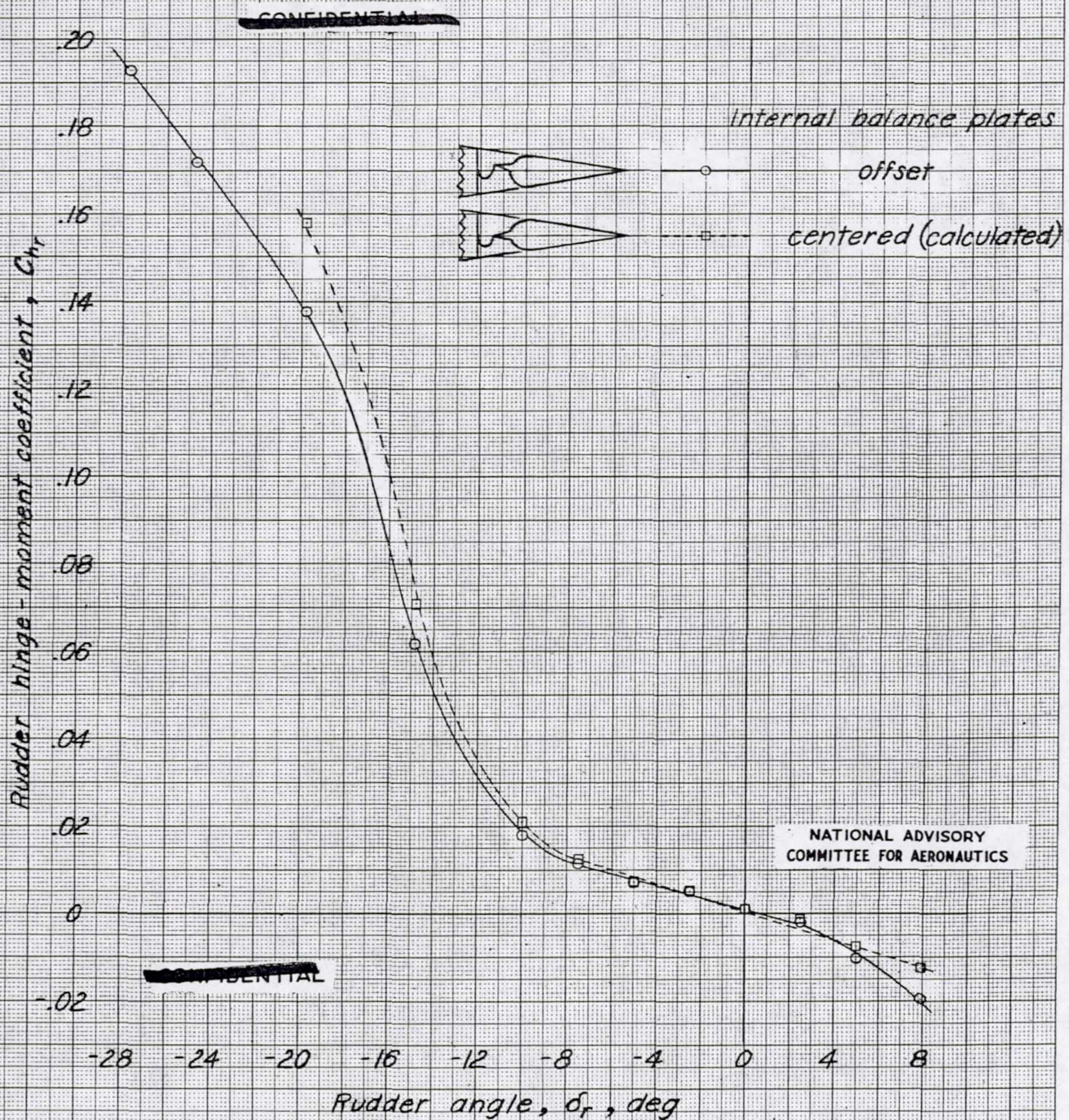
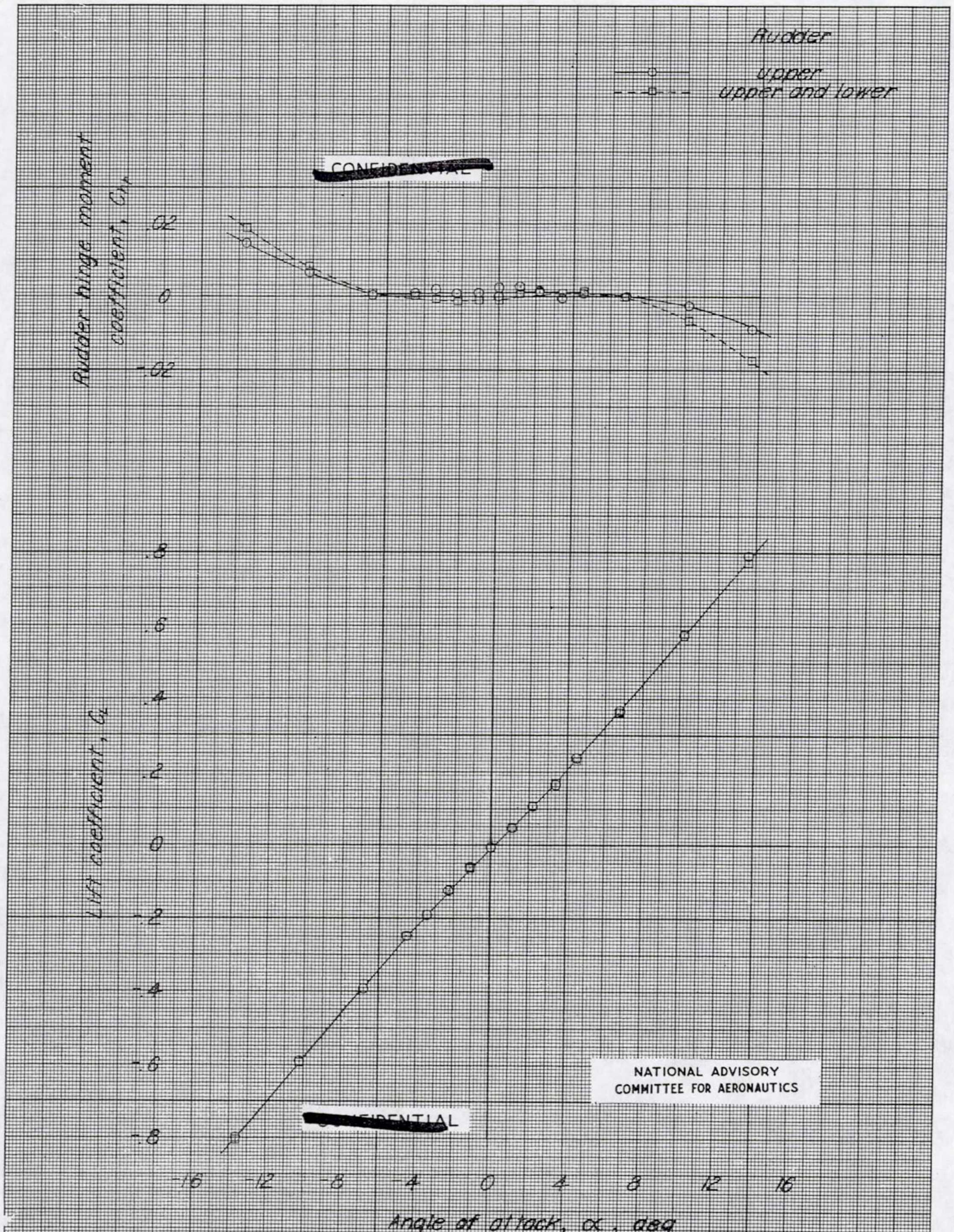
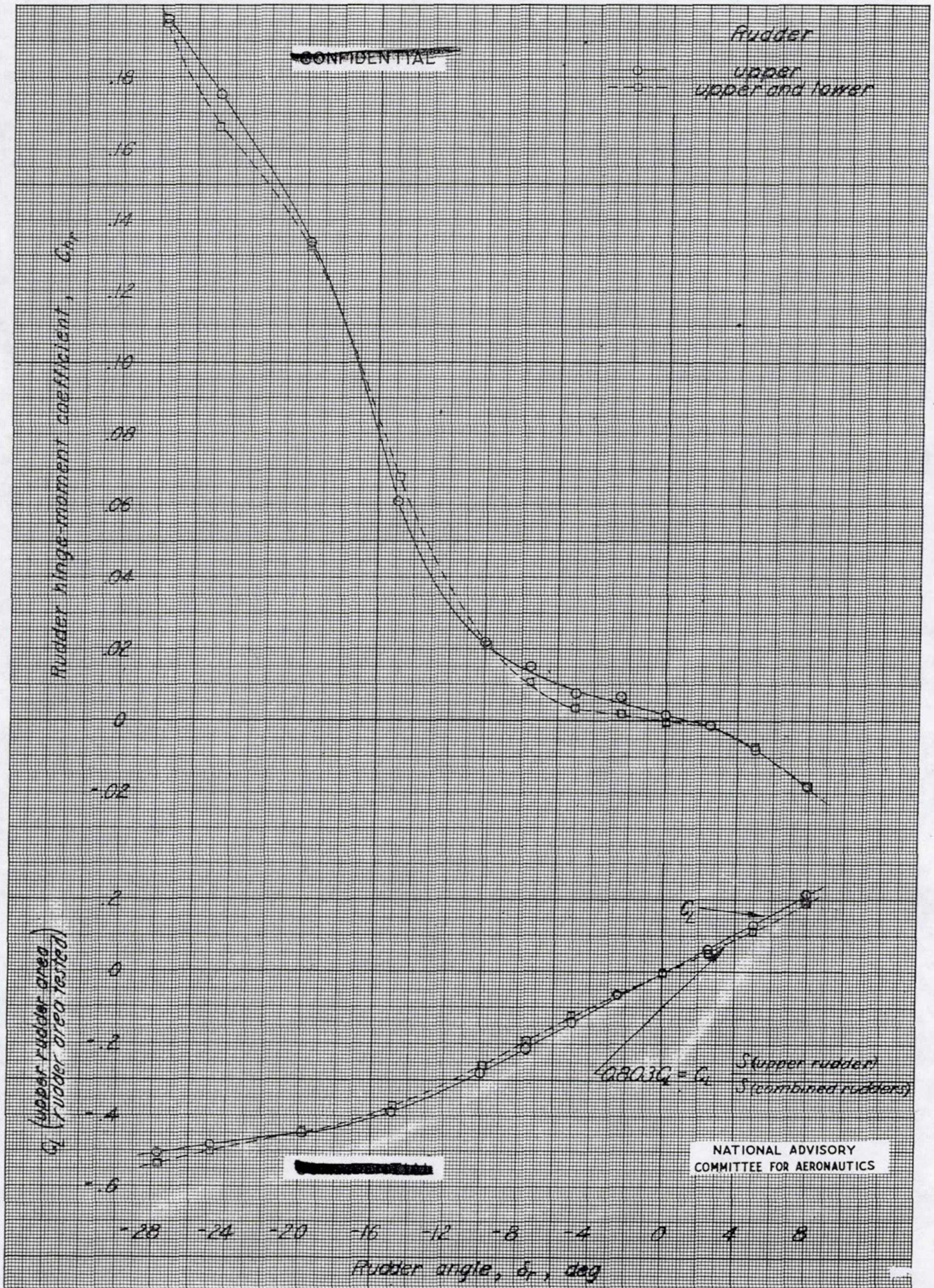


Figure 9.- Effect of offset location of internal balance plates on rudder hinge-moment coefficients of XF-12 vertical tail model with roughness strips at 0.20 c. Upper rudder alone utilized; cover plates in normal position; $\alpha = 0°$, $\delta_t = 0°$.



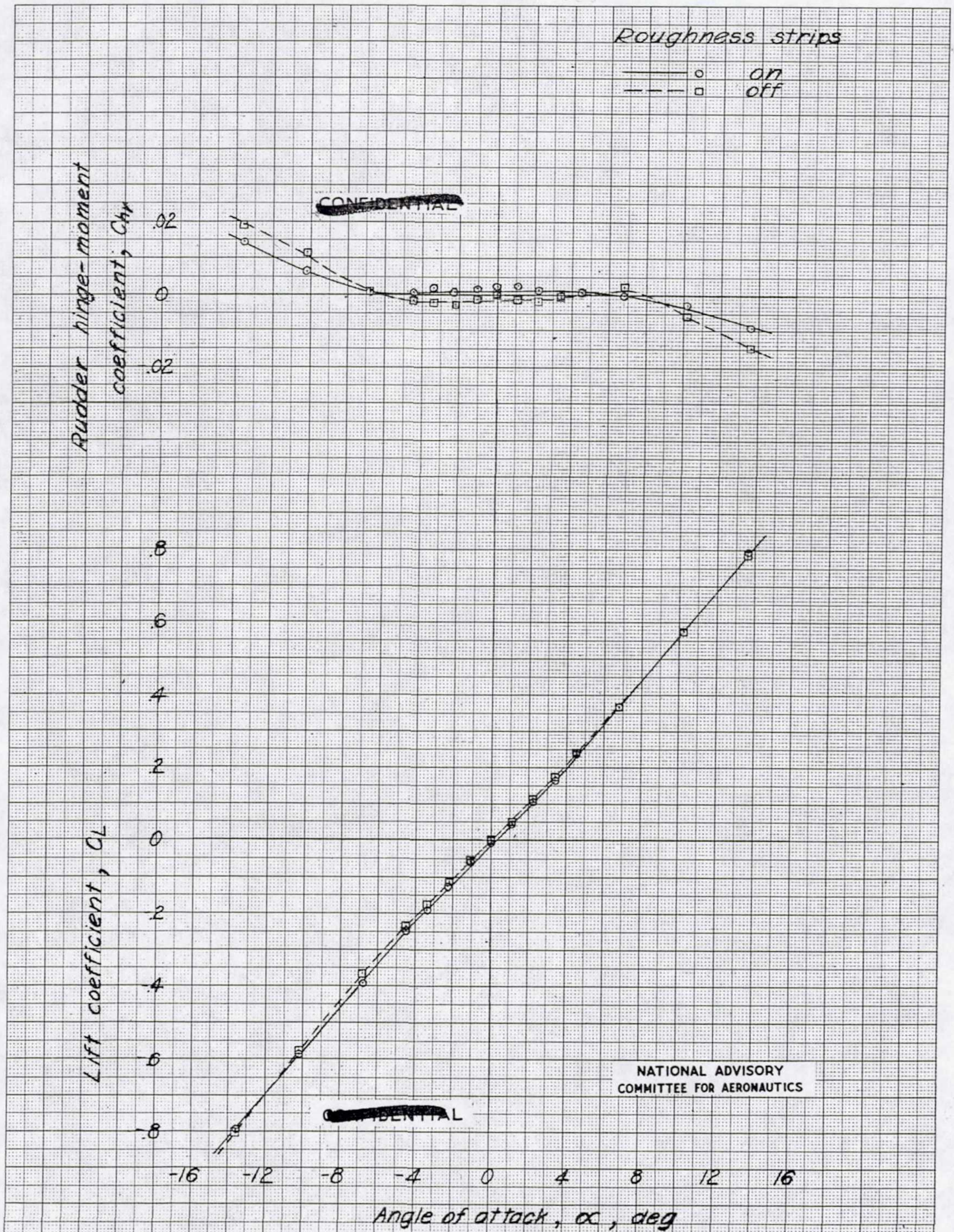
(a) δ_r, deg = 0.

Figure 10. - Aerodynamic characteristics of the XF-12 vertical tail model for two rudder areas. Roughness strips at 0.20c; cover plates in normal position; $\delta_t = 0°$.



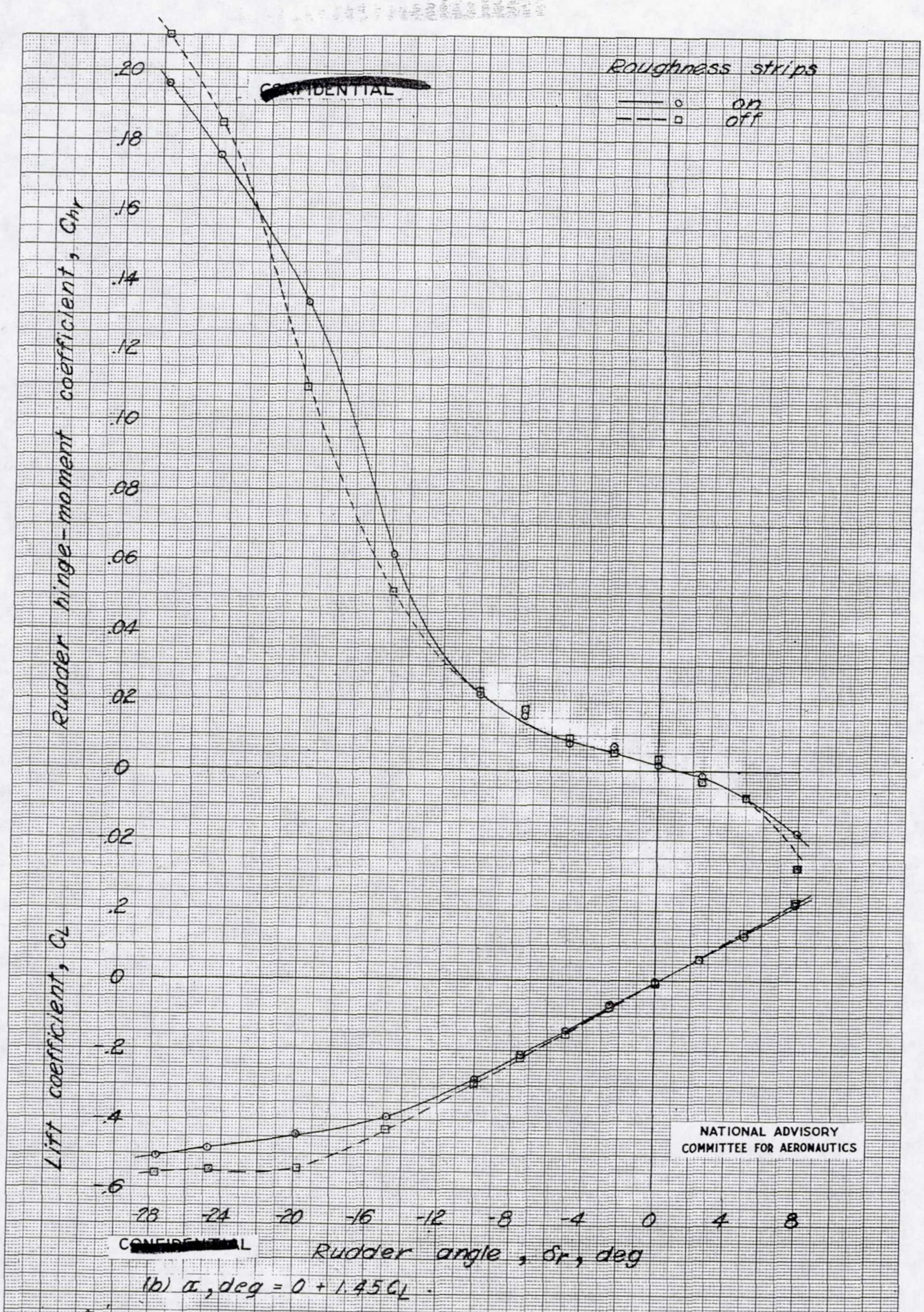
(b) α, deg (upper rudder) = 0 + 1.45 C_L
α, deg (combined rudders) = 0 + 1.70 C_L

Figure 10.- Concluded.



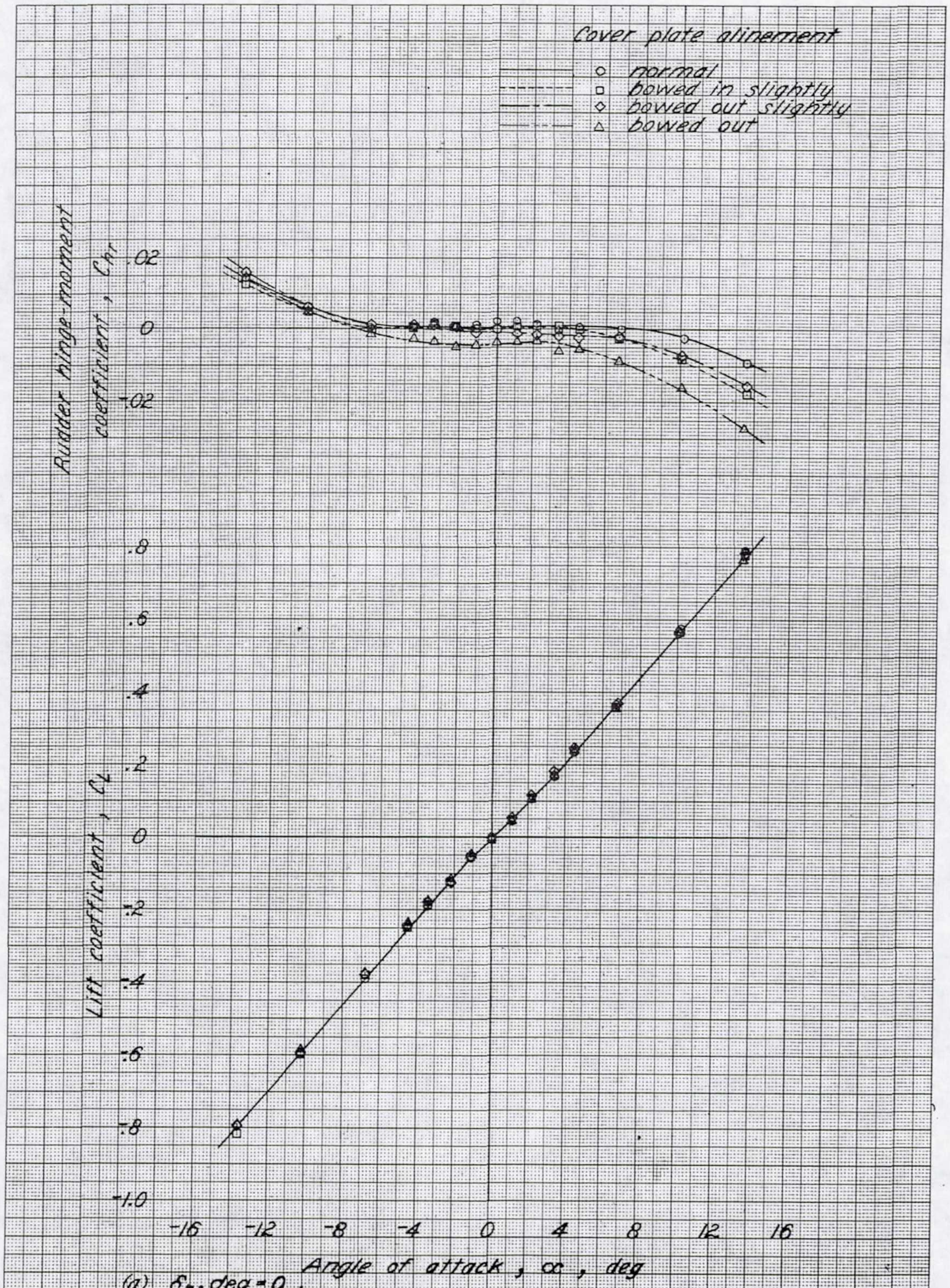
(a) δ_r, deg = 0.

Figure 11.- Aerodynamic characteristics of the XF-12 vertical tail model for roughness strips on and off. Upper rudder alone utilized; cover plates in normal position; $\delta_t = 0°$.



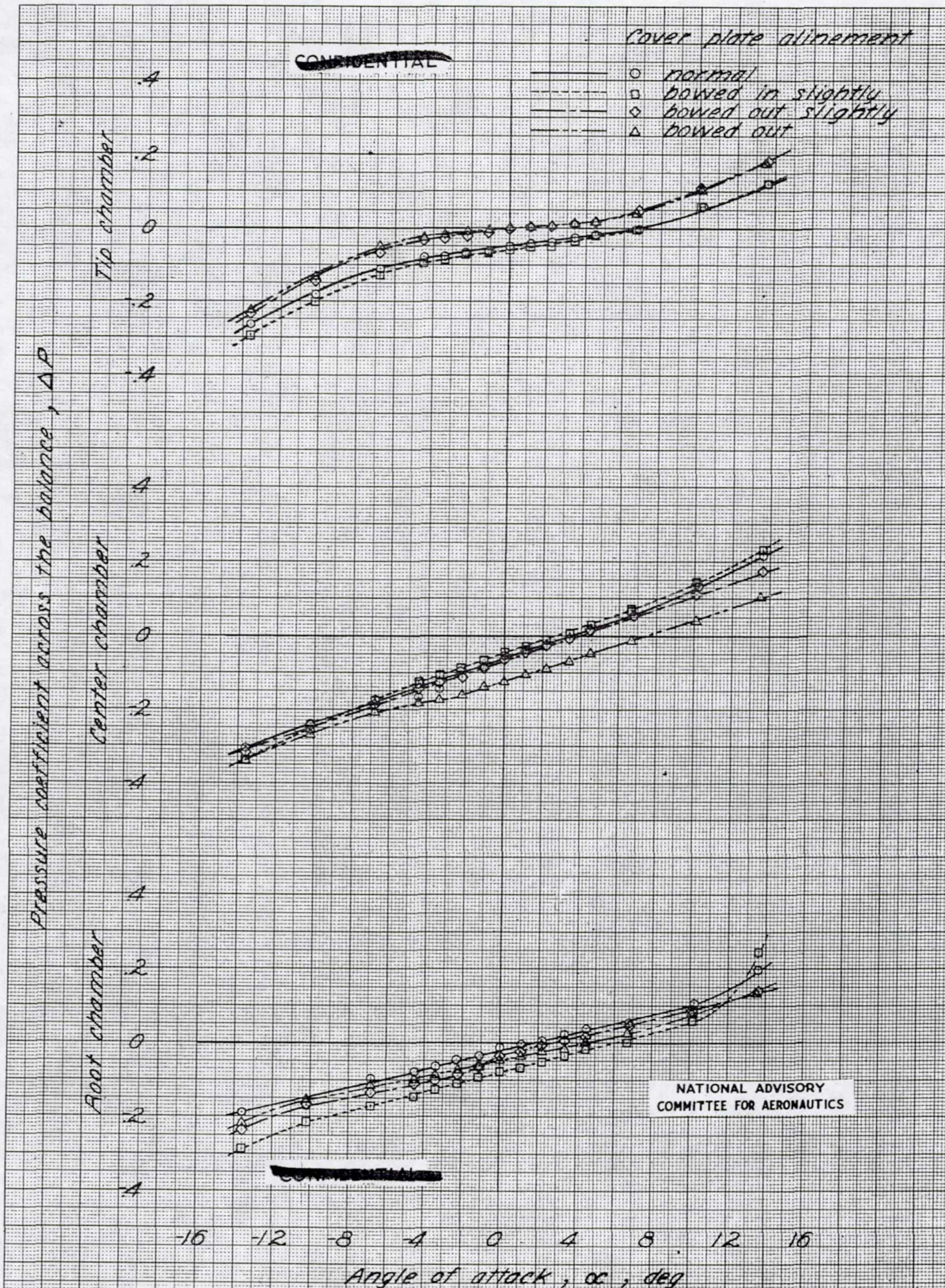
(b) α, deg = 0 + 1.45 C_L.

Figure 11.- Concluded.



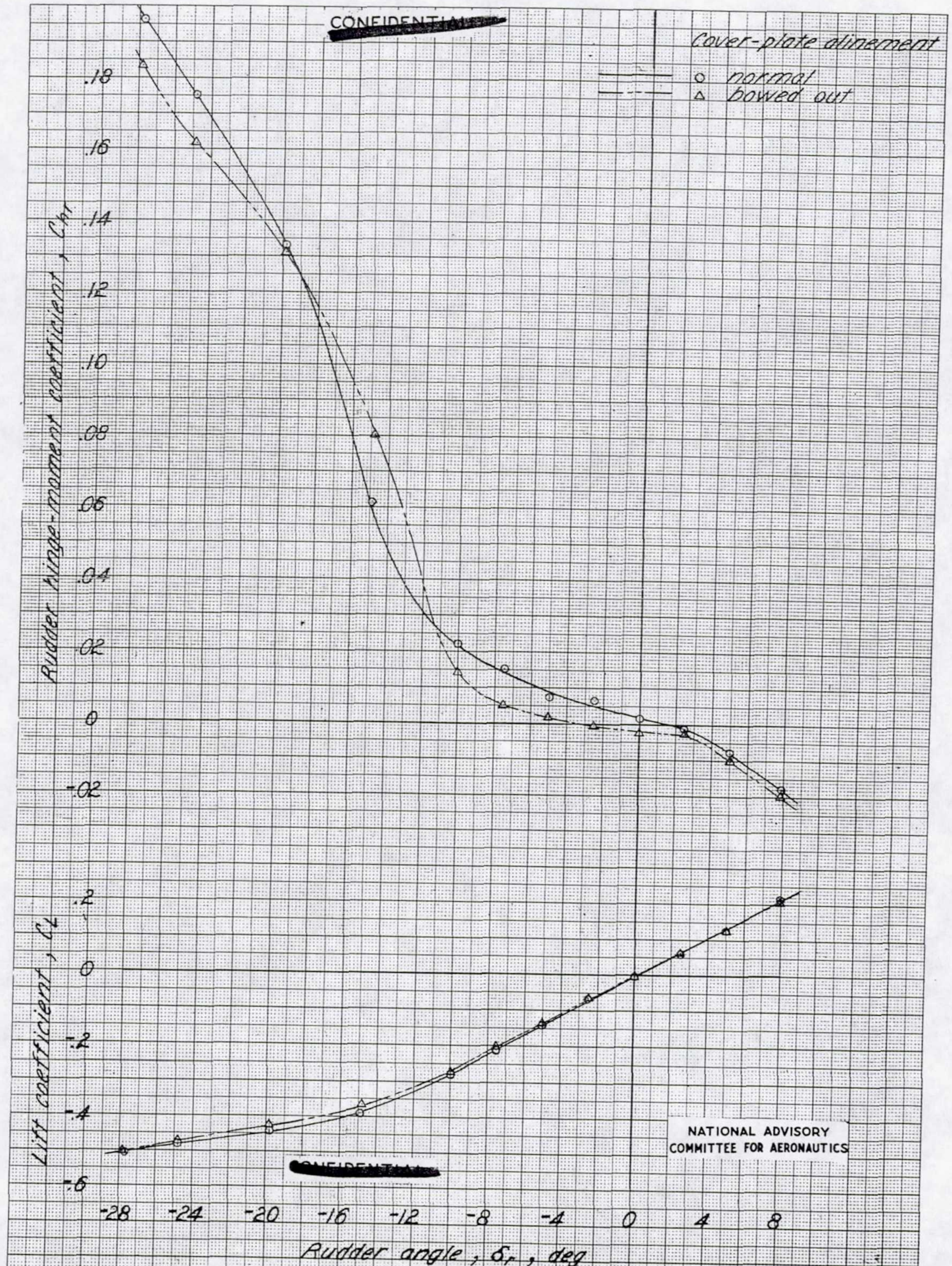
(a) δ_r, deg = 0.

Figure 12. - Aerodynamic characteristics of the XF-12 vertical tail model for various cover plate alinements. Upper rudder alone utilized; roughness strips at 0.20c; $\delta_t = 0°$.



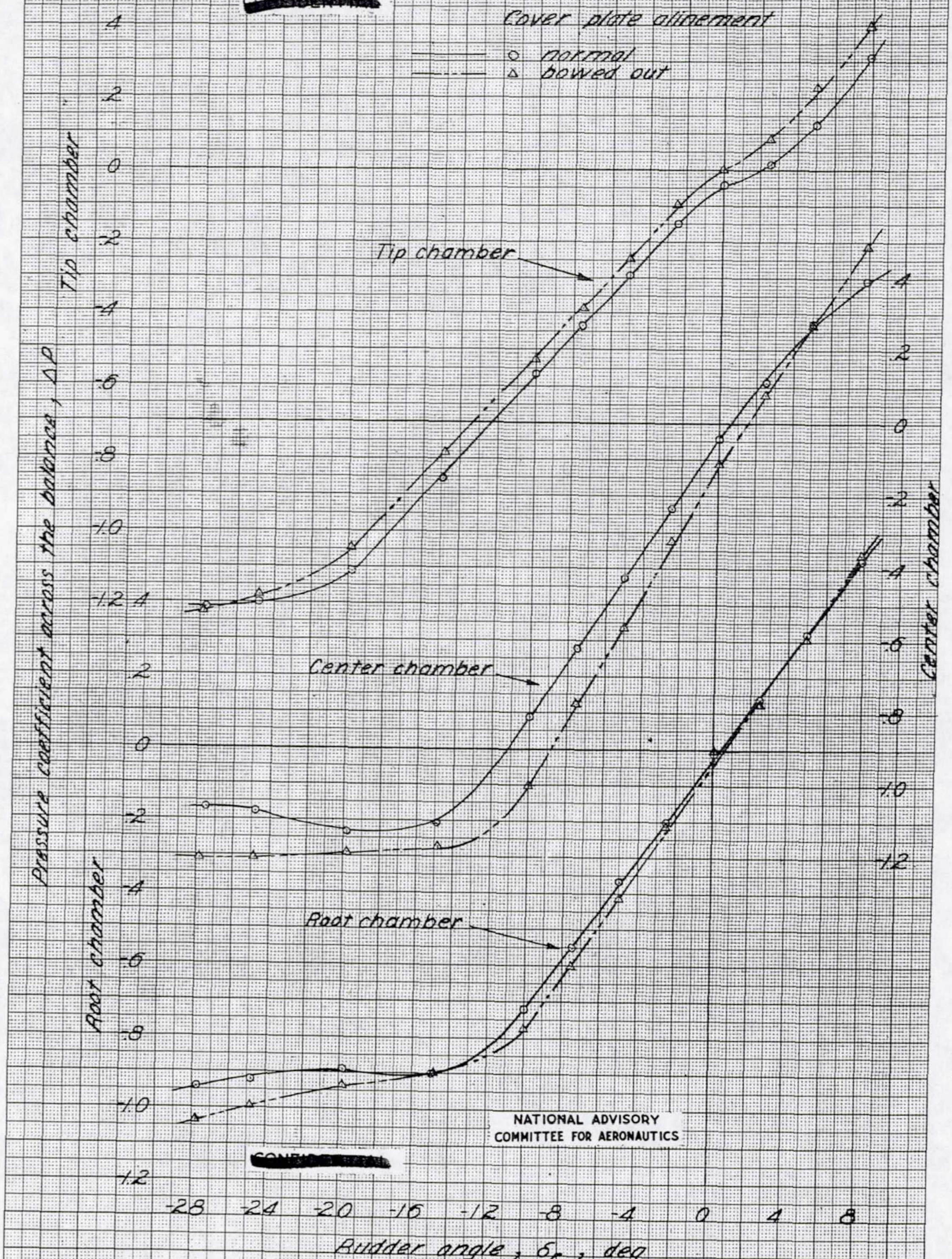
(a) Concluded.

Figure 12.- Continued.



(b) α, deg = 0 + 1.45 C_L

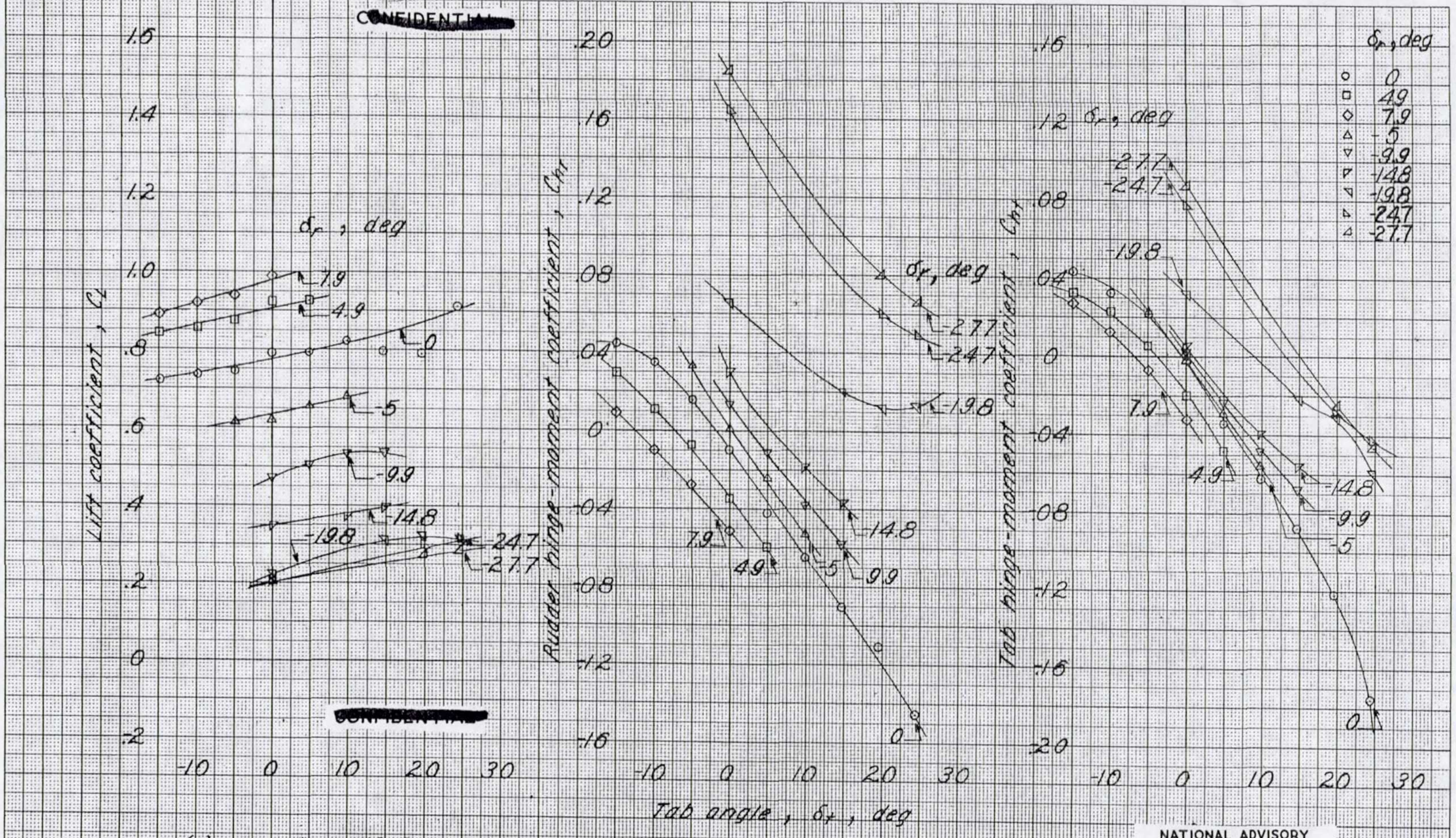
Figure 12. - Continued.



(b) Concluded.

Figure 12. - Concluded.

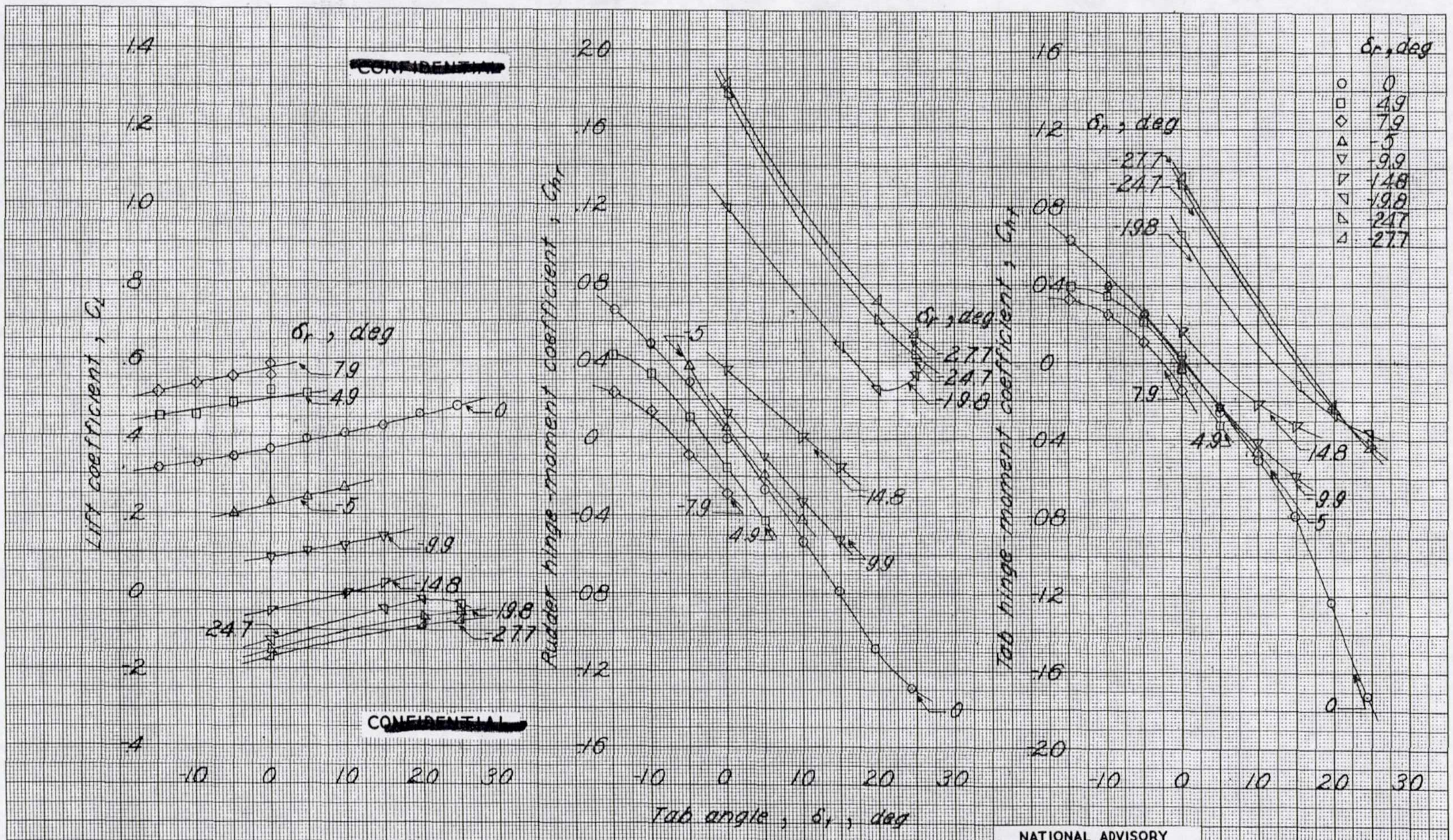
[redacted]



[redacted]

(a) α, deg = 12.4 + 1.45 C_L.

Figure 13. - Tab tests of the XF-12 vertical tail model with roughness strips at 0.20c. Upper rudder alone utilized; cover plates in normal position.



(b) α, deg = $6.2 + 1.45\,C_L$.

Figure 13.- Continued.

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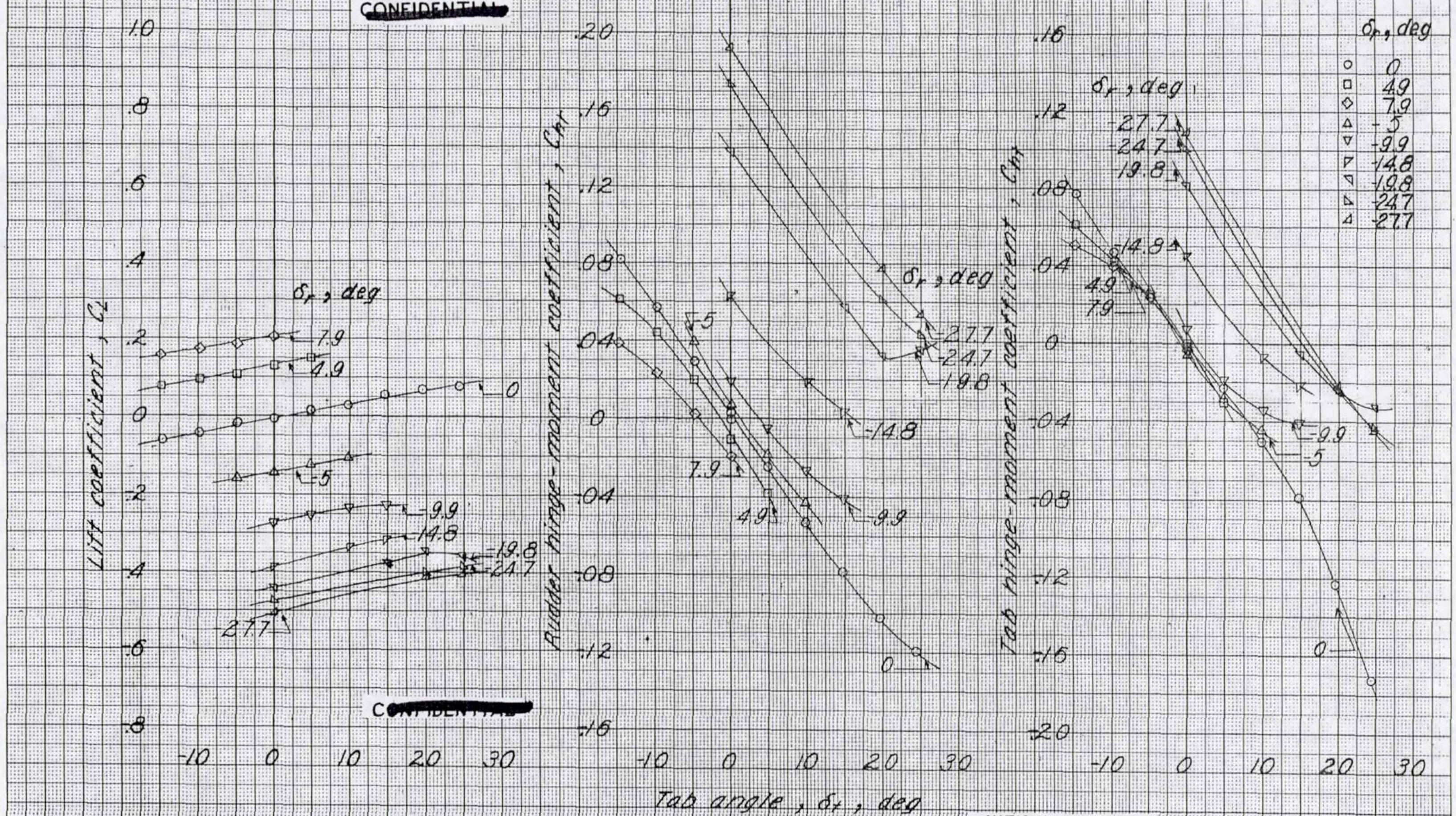

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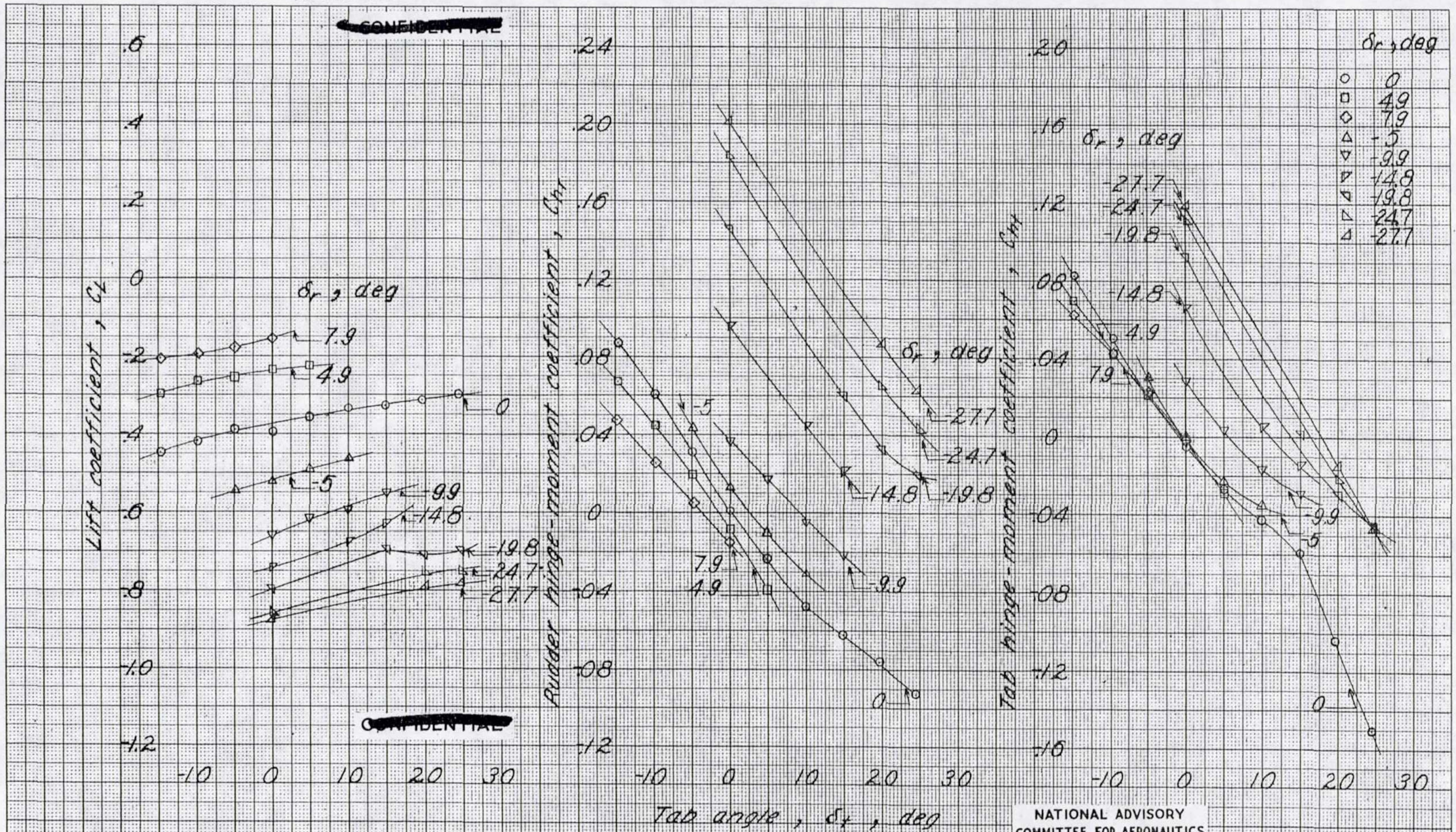
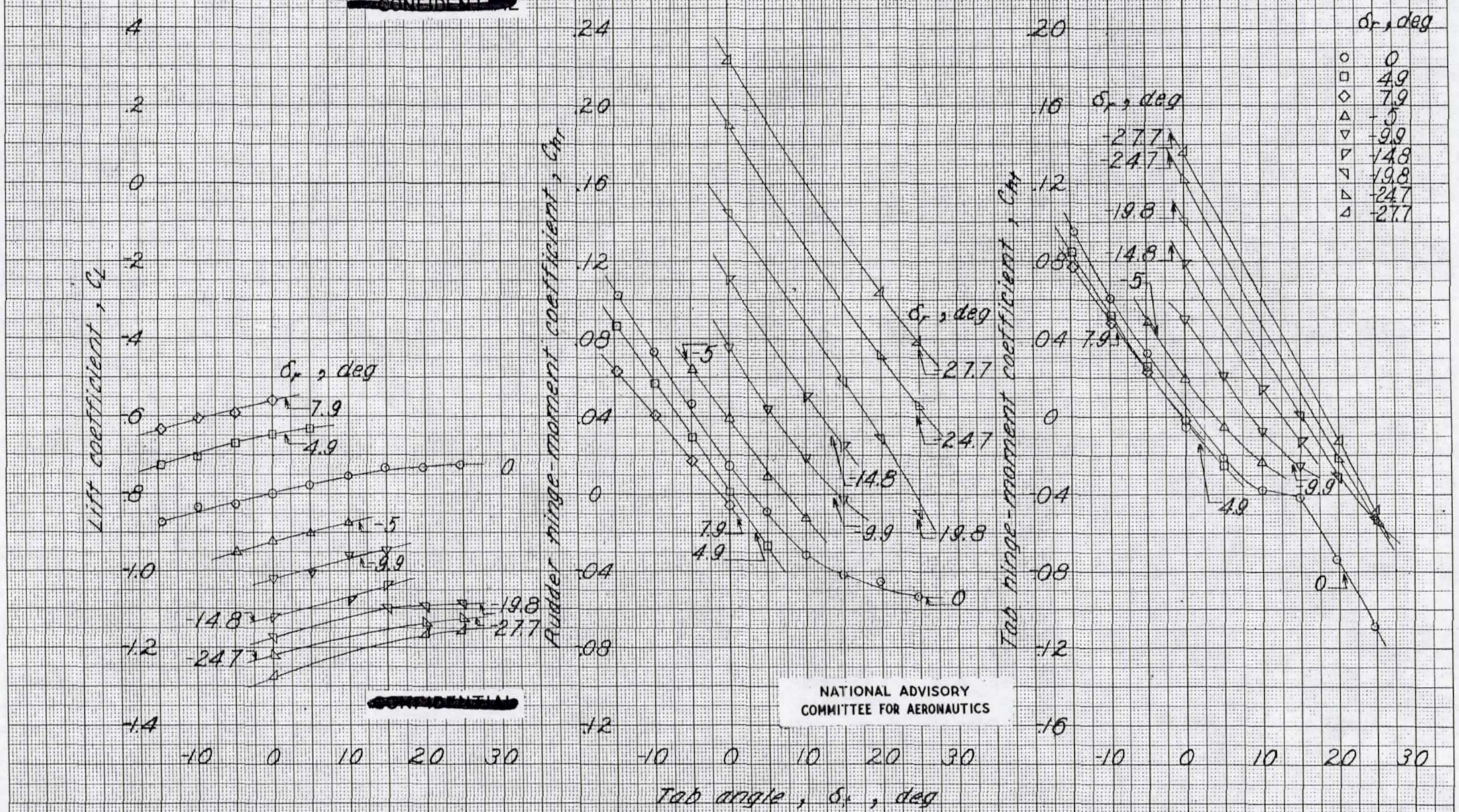
(c) α, deg = $0 + 1.45\,C_L$.

Figure 13. - Continued.



(d) α, deg $= -6.2 + 1.45\,C_L$.

Figure 13. — Continued.



(e) α, deg = $-12.4 + 1.45C_L$.

Figure 13.- Concluded.

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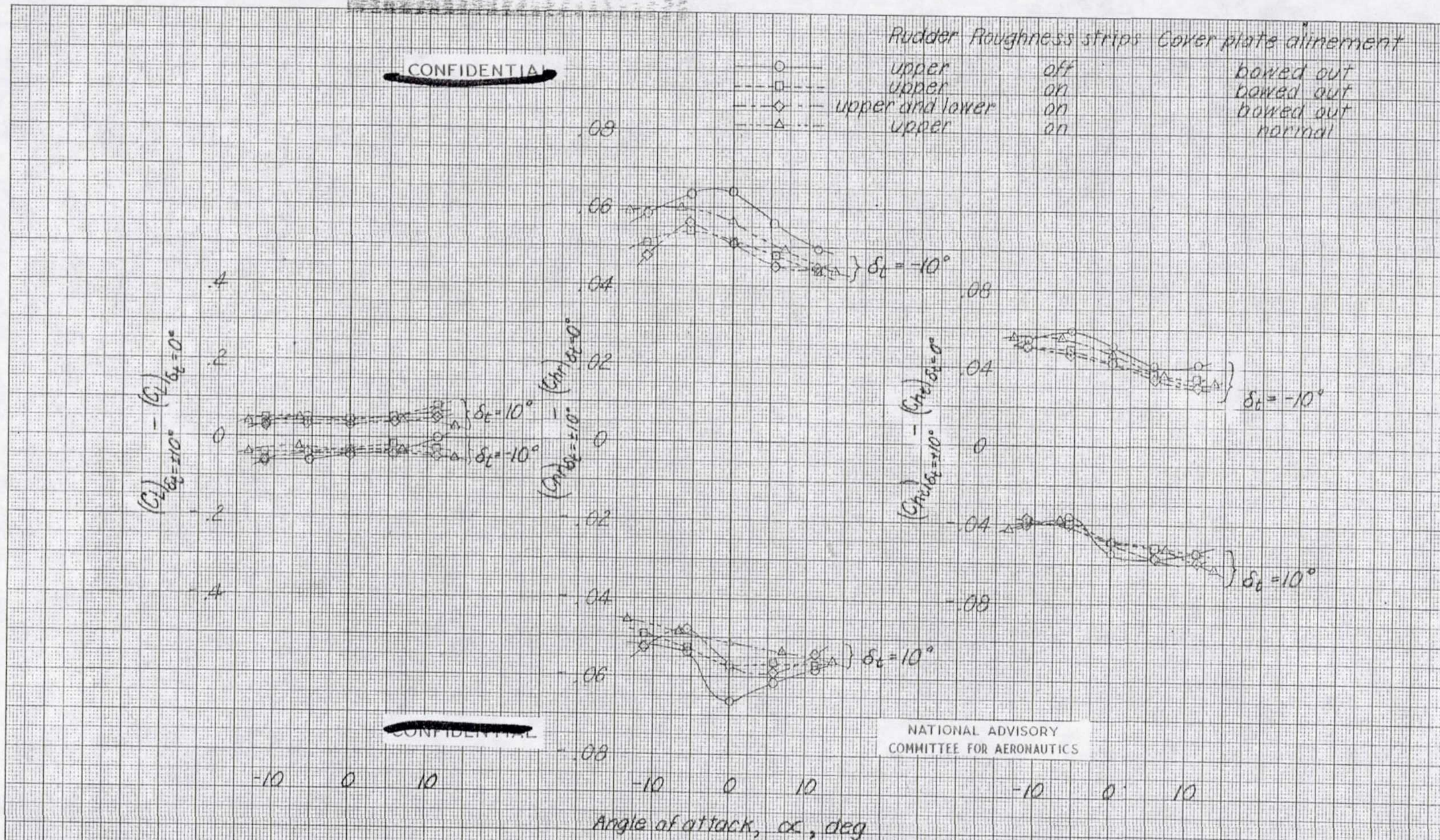

(a) δ_r, deg = 0.

Figure 14 .- Effects of various model configurations on tab characteristics of XF-12 vertical tail model.

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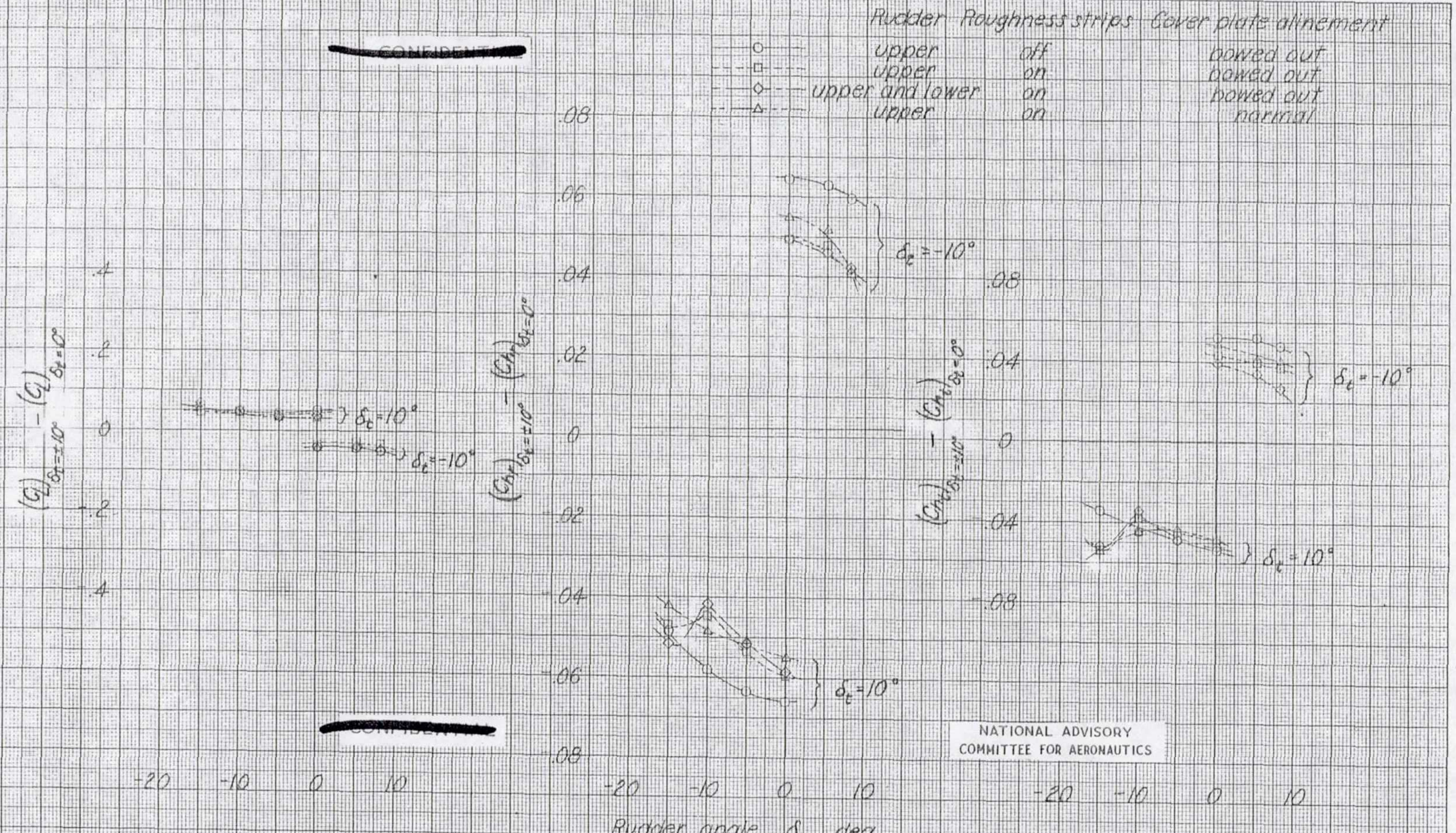

(b) α, deg = 0.

Figure 14.- Concluded.

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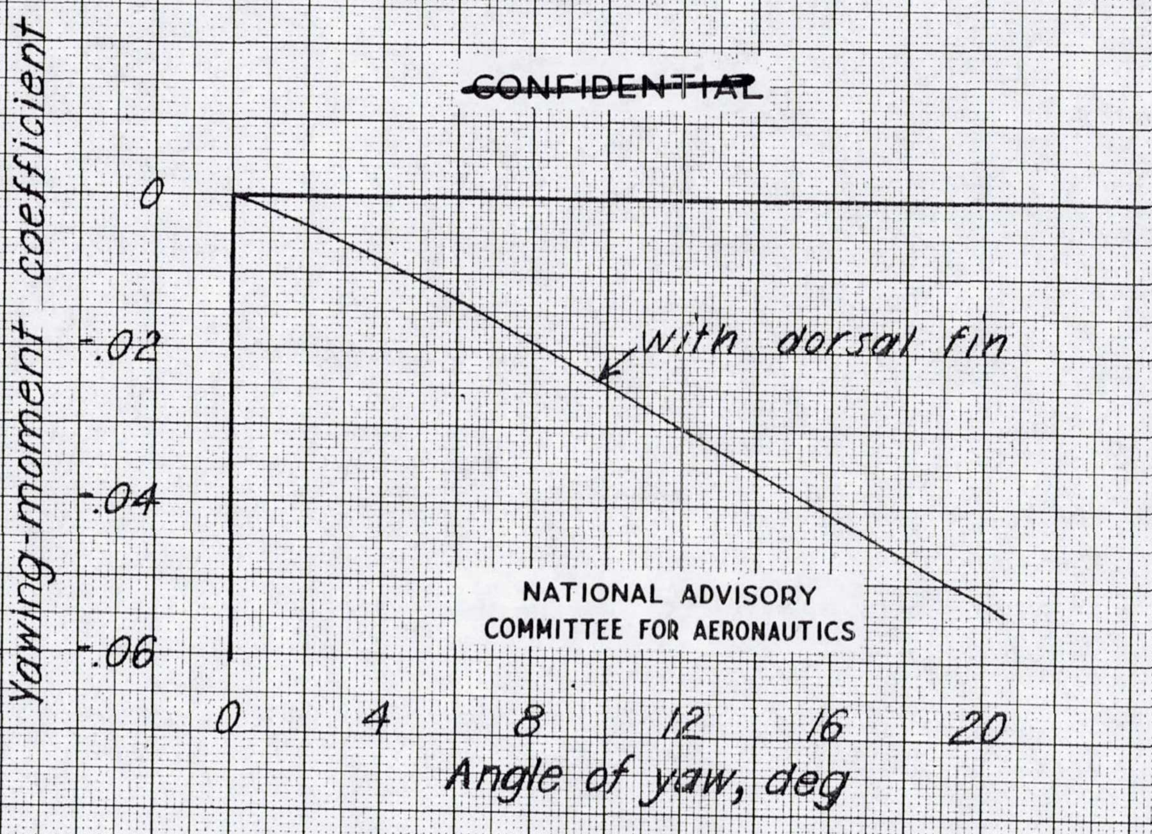

Figure 15.- Estimated directional stability characteristics of XF-12 airplane. $\delta_r = 0°$, $\delta_t = 0°$, windmilling propellers.

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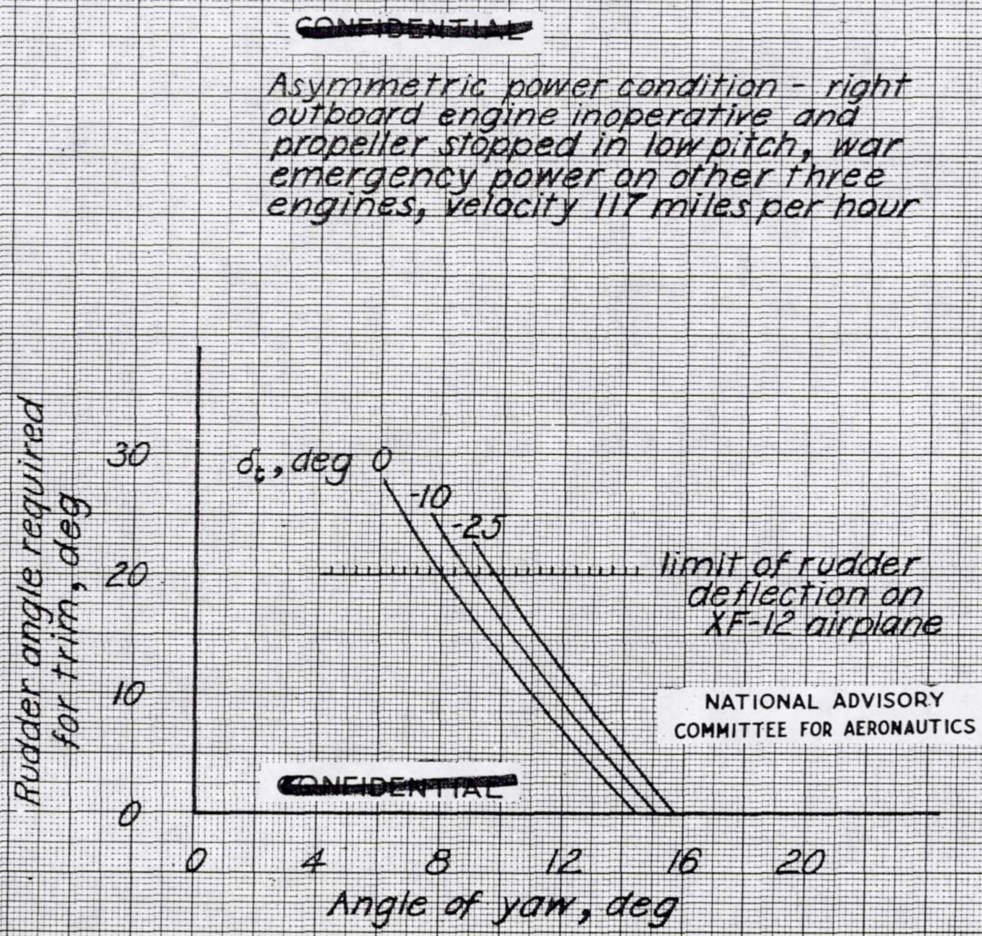

Figure 16.- Estimated rudder deflections required to balance an asymmetric power condition at various angles of yaw of XF-12 airplane. Upper rudder alone utilized.

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